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ROCKET PROPULSION EQUIPMENT

BENDIX PRODUCTS AEROSPACE DIVISION • SOUTH BEND 20, INDIANA

Bendix

Report No. BPAD-863-14385

March 10, 1962

Services to Generate Engineering Data on the Behavior of Plastic Composite Structures Under Various Conditions of Stress

Contract NOw-61-0488-c-(FBM)

PHASE II

FINAL REPORT

Released to Armed Services Technical Information Agency Without Restrictions or Limitations

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SECTION I

INTRODUCTION

This report covers utilization of pre-preg materials reported in Phase I Report No. BAE-863-14367. These materials were used to fabricate both seven inch diameter pressure vessels and eighteen inch multi-ported cases. The cases were built to develop construction techniques applicable to pre-preg materials and obtain the degree of correlation between split "D" ring tension tests and actual performance in pressure vessels.

Pre-preg materials have opened completely new horizons in ways to locate precisely the desired amount of added reinforcements in a rocket case. These added reinforcements are of little value if their outer extremities cannot be faired out to provide a smooth transition into the base structure. One of the major advantages of pre-preg materials is the ease with which the designer can provide for a scarf type joint. The techniques developed during this program were aimed specifically at reducing the stress concentrations in areas such as knuckle region, on center port openings, off center port openings (nozzle) and termination of tape ends.

The necessity of having an evaluation chamber which would be programed to prevent premature failure in the end dome regions without effecting the balance of material in the cylindrical section was one of the reasons for developing the techniques used.

SECTION II

SUMMARY

This Phase II report of the contract is divided into several different activities; namely, tensioning and packaging, reducing stress risers, the fabrication of seven-inch pressure vessels, eighteen-inch rocket cases, and bending tests.

Section III explains the methods used for the packaging of pre-preg tapes and rovings and RECOMMENDATIONS for tensioning these materials.

Section IV discusses stress concentrations due to the termination of tape ends and gives methods for controlling the stress risers during fabrication.

Section V describes the seven-inch diameter pressure vessel used in this program and discusses the analytical and experimental methods used to derive the end dome configuration. The data of all cases tested are listed.

Section VI gives the design concept for off-center port reinforcements. These reinforcements were incorporated in eighteen-inch cases which were scaled up from the basic pressure vessel (Section V).

Section VII presents a method of utilizing a filament wound cylinder which can have a pure bending moment applied without special machining operations. Data for specimens tested are listed.

Section VIII gives the results of a statistical analysis to determine the degree of correlation between "D" ring tests and their respective cases described in Section V.

SECTION III

TENSIONING AND PACKAGING OF PRE-PREG MATERIALS

PACKAGING OF PRE-PREG MATERIALS

Roving

The generally accepted method of packaging pre-preg roving is to re-spool the roving, after impregnation with resin, onto the same type of container and with the same type of level wind system which was used for the initial packaging of dry roving at the glass mill.

Usually this type of packaging does not require an interleaver between the rovings to provide separation during unspooling. If broken monofilaments are left on the surface of the package, the unspooling of the succeeding layers of material is at the opposite helix angle, thus providing a self-cleaning action. (See Figure 3-1)

Tapes

Two systems are used for packaging pre-preg tapes (a tape consists of a number of yarns laid parallel to one another without crossover of the ends of the yarn).

A. One system is similar to the packaging used for pre-preg rovings. Depending upon the characteristics of the resin system, an interleaver may be required to provide separation of the material during removal from the package. (See Figure 3-2).

B. The other system is often referred to as a "planetary wind". This consists of winding the pre-preg tape such that each layer lays on top of the tape from the preceding revolution - same as a roll of friction tape. This method of winding requires an interleaver for the unspooling operation. When the length of a tape exceeds approximately 100 yards, side plates are required to protect the roll from telescoping sideways.

TENSIONING

In order to provide the proper nesting of the pre-preg material on the winding arbor, high winding tension and/or heating of the material was required at time of winding.

The basic setup for tensioning was the same for either pre-preg tape or roving. The system consisted of inserting a brake drum between the supply spool and winding arbor. A contact arc of approximately 270° on a 6-inch diameter drum provided an adequate

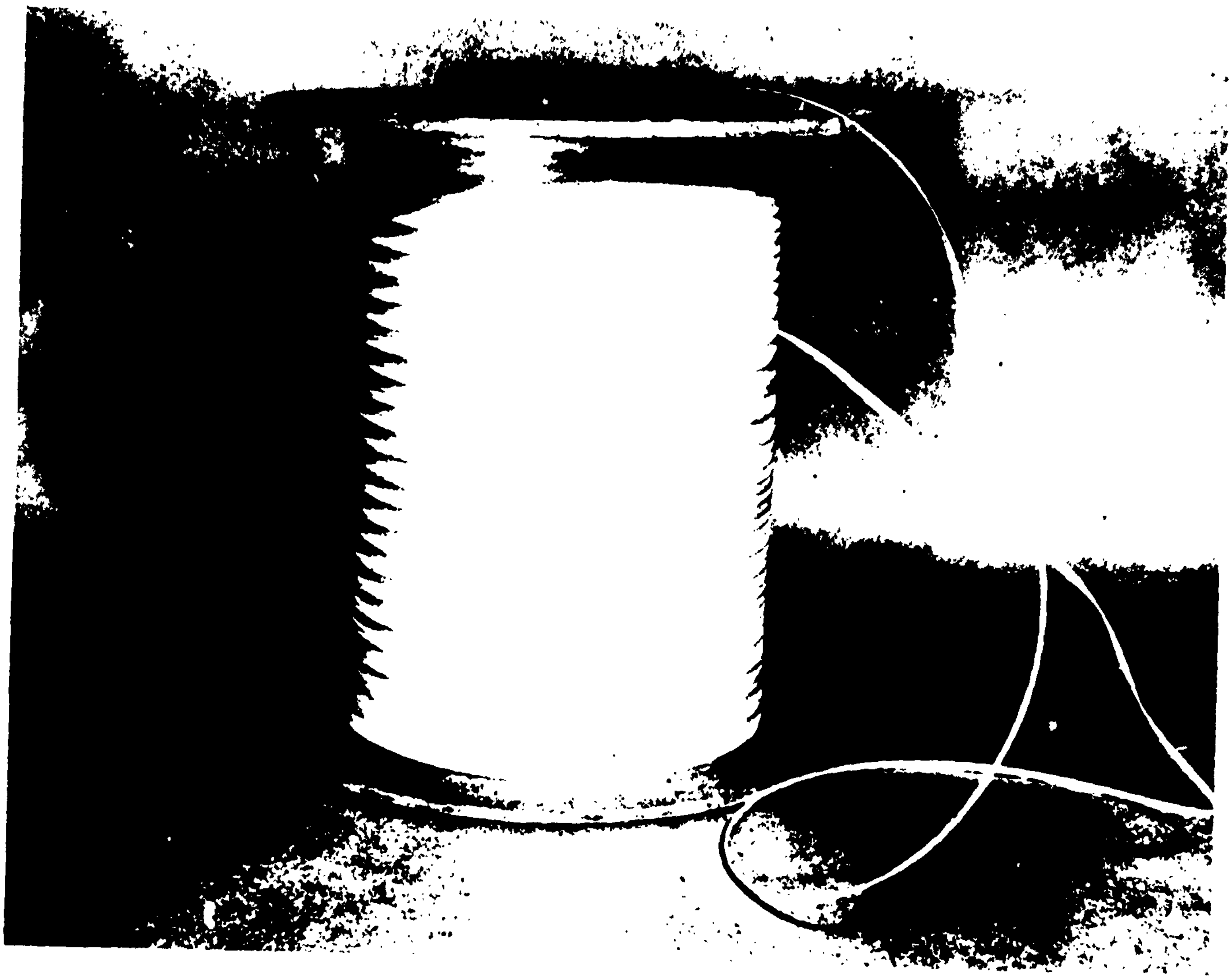


Figure 3-1. Roving Package Without Interleaver

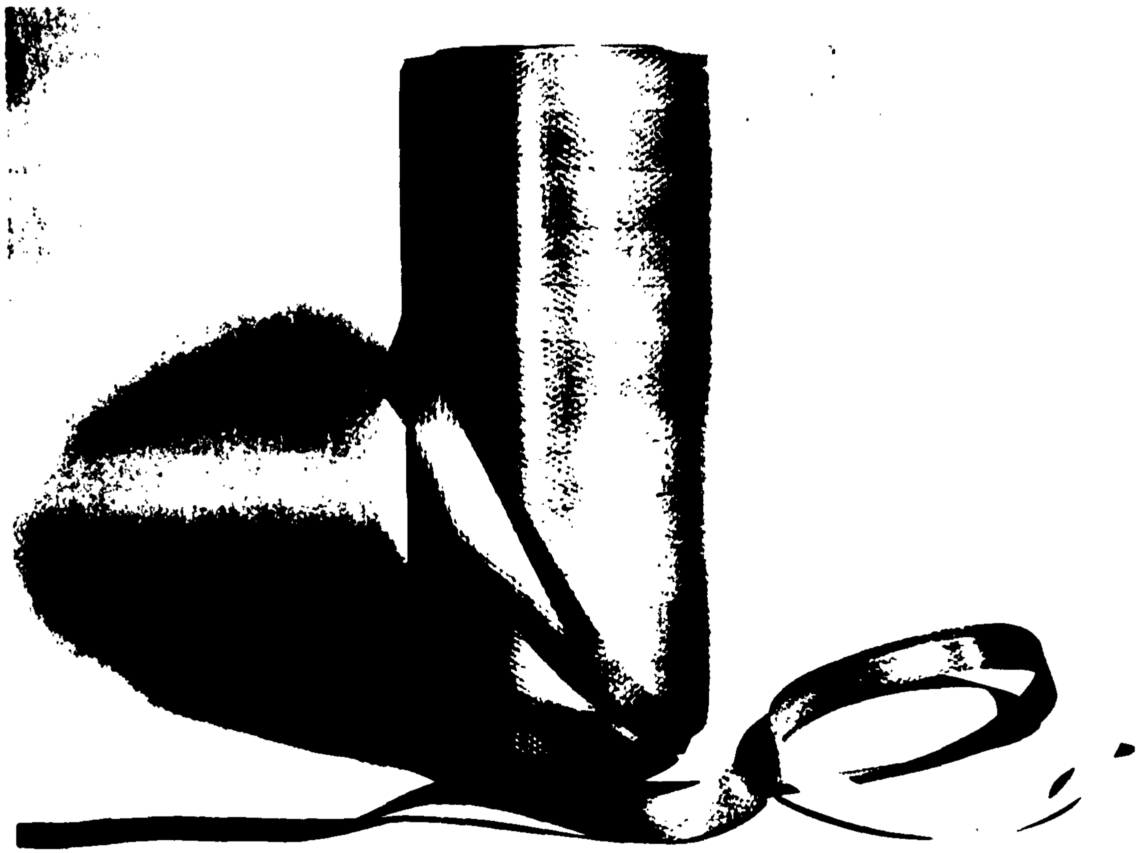


Figure 3-2. Tape Package With Interleaver

frictional surface for tensioning. The surface of the drum should be smooth and a method provided to remove any broken monofilaments that may have adhered to the surface of the drum. At least two guide rollers were required at the brake drum. These rollers may be as small as 1 inch in diameter and teflon coated to prevent resin adherence to the surface. See Phase I Report No. BAE-863-14367.

The type of brake described above requires that an initial tension be applied to the incoming material to prevent its slipping on the brake drum. The tension required is a function of the drum diameter and the frictional coefficient of the drum surface. A tension of approximately 0.1 ounce per end, (yarn or roving) applied to the material before entering the brake, will usually provide the necessary activating force. This low tension was obtained by applying a brake to the supply package.

ALWAYS apply the minimum tension possible to the supply package.

Each individual tape or roving will require an individual tensioning device. When tape construction was used, the width of the tape was the same as the width of the grid pattern, thus, only one brake setup was required. (See Figure 3-3)

For pre-preg roving construction two 20-end pre-preg rovings were laid side by side. This required two tensioning devices for forming a 40-end pre-preg roving band. (See Figure 3-4)

<u>Recommendations For Tensioning</u>

1. Tensions normally required for a winding process, SHOULD NEVER be applied to the supply package.

2. Tension should be applied to the material after it leaves the supply package, and an individual tensioning device should be provided for each supply package.

3. When using a tape width greater than approximately 1/2 inch, the interleaver (if used) should remain with the tape through the tensioning head and be removed after the pre-preg tape is on the winding arbor. This will help provide a constant tape width. When the winding arbor was more than 2 feet from the tensioning device, a wide tape had a tendency to rope.

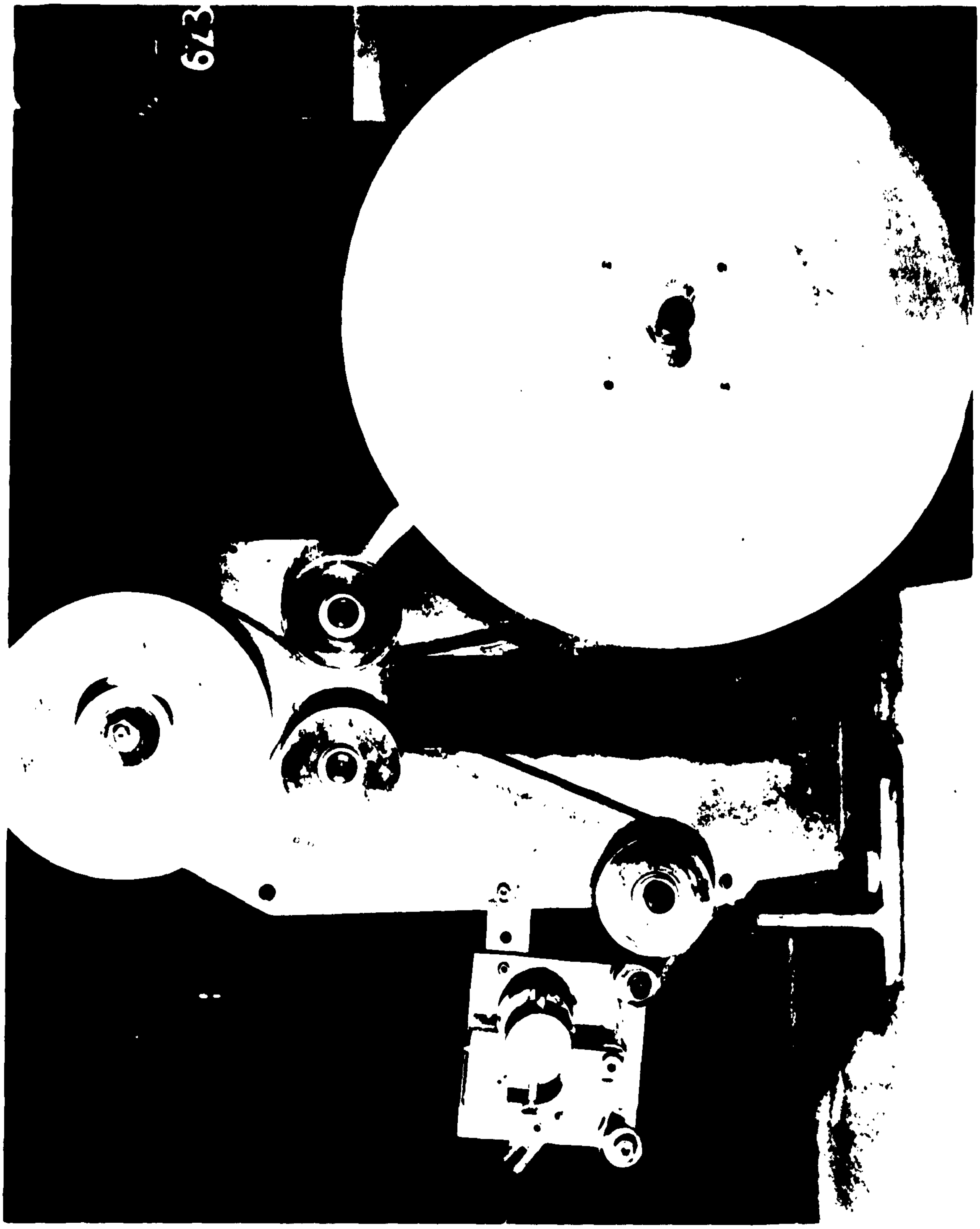


Figure 3-3. Tape Brake Setup

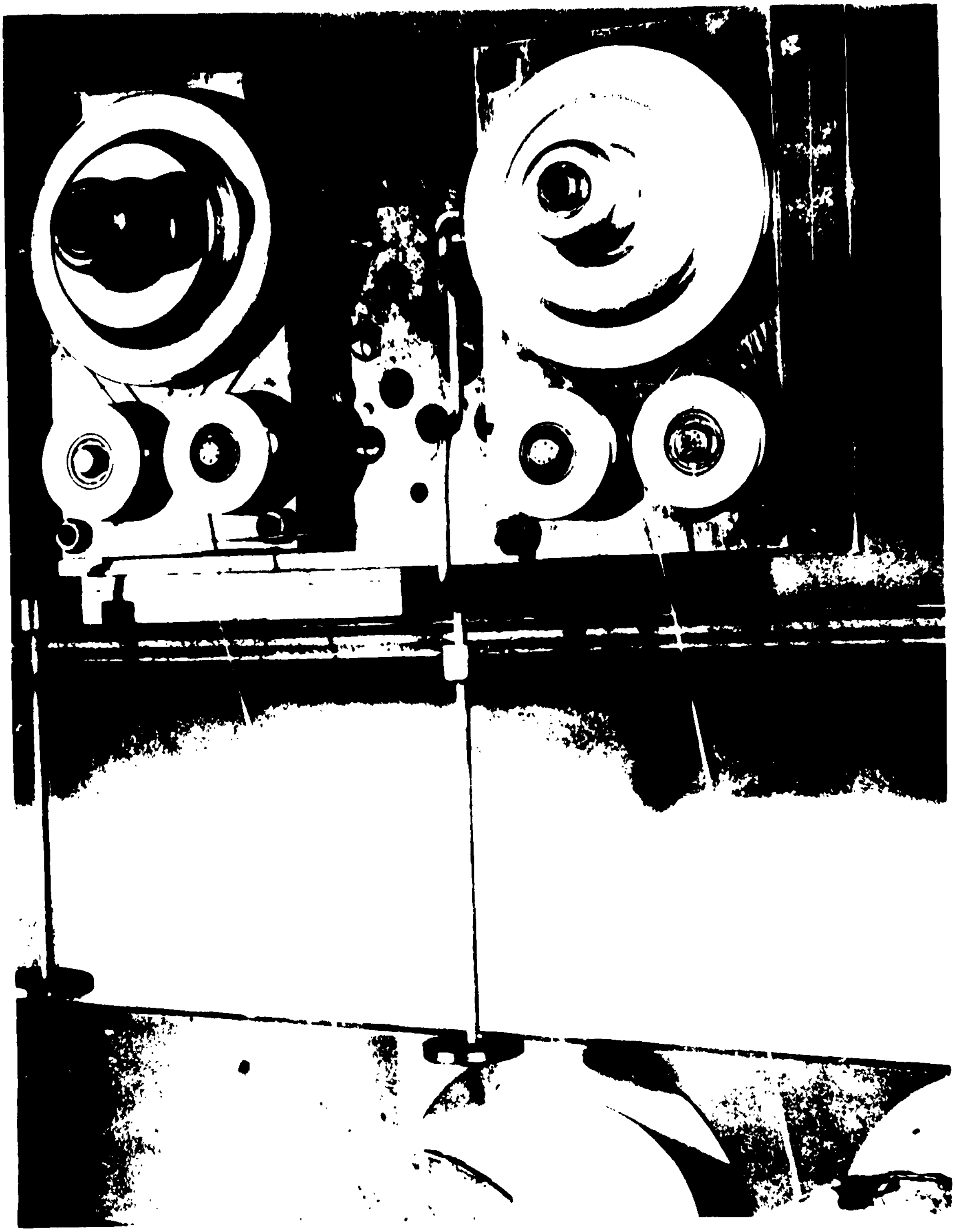


Figure 3-4. Tensioning Device for 40-End Pre-Preg Roving Band

SECTION IV

REDUCING STRESS RISERS

Even though a case of excellent design has been fabricated with high quality materials on precise wrapping equipment, it could be erratic in quality if the importance of proper termination of tape ends is overlooked. To approach the problem from a viewpoint of having placed sufficient material in the windings to carry the loads in the structure, can easily lead to severe stress risers. When a design is analyzed to determine the deformations of ALL sections of the structure, the importance of the termination of tape ends is readily apparent. The deformation studies must be conducted on the structure as it will be "Actually Fabricated" by the production winding facility.

Normally, the initial design is based on wrap pattern calculations, number of windings, etc., to carry the required loads without the need to know specific processes of the particular fabrication source. Consider the winding of an ABL - 6400 qualification pressure vessel which normally has four thicknesses of longitudinal material and five thicknesses of circumferential material. An overlap of approximately 3 inches is used to develop full strength of a loose end of tape. If this joint is located at the PT point there would be five layers of material thickness in the joint and only four thicknesses of material in the adjoining area. The deformation would be 20 per cent less in the joint area. The magnitude of the stress riser could be many times larger than the ratio of the deflections when located in a critical area. This same joint located at the polar opening is of a relatively minor magnitude.

The methods used are by no means the only approaches which can be implemented to reduce stress concentrations. The important item is to be aware of the problems that could arise if there is not close alliance between the design concept and the specific shop practices used during construction.

CIRCUMFERENTIAL WINDINGS

The circumferential material is applied to the arbor as a tight spiral wind. A winding machine cross head advances one tape width for each revolution of the arbor. When tape width exceeds approximately 1/2 inch, it is desirable to trim off the ends of the cylinder so that the end of the tape is spread around the cylinder.

This is provided for by starting the material onto the arbor before the PT and wrapping past the PT on the other end. The excess material is then trimmed parallel to the points of tangency and easily removed by step cutting. The ends of the tape should be held in place with a pressure sensitive tape, such as mylar, until these areas are ready to be covered with the succeeding windings. (See Figure 4-1)

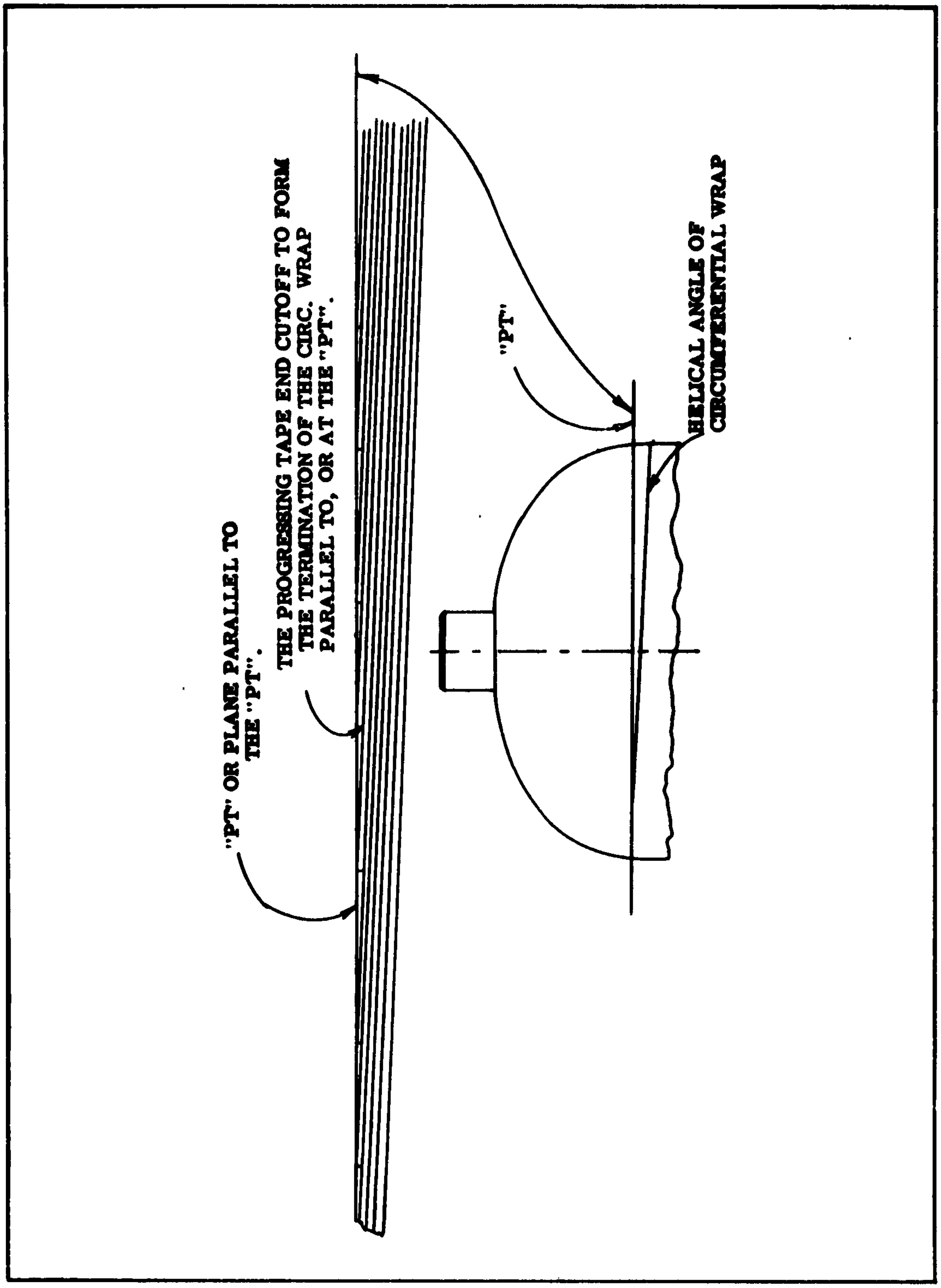


Figure 4-1. Method of Fairing Circumferential Tape Ends

Width of Circumferential Windings

The basic width of a circumferential winding is normally considered to be the distance between points of tangency. Past experience has shown that if all the cylindrical windings are maintained at the same width, a high stress riser will occur at the point of tangency. Normally, when circumferential material is applied, at least two layers of windings are required. The logical approach would be to start at one PT, traverse to the other PT and return (without cutting the tape) to the starting point. This method works out well for narrow widths of tape; however, when the tape width approaches 1/2 inch, an undesirable kink is placed in the tape at the point where it starts the return traverse. The loss in strength due to the kink is probably much less than that which results from two cut ends at the other end of the cylinder. Because the geodesic path is not maintained at the turn around point, a kink and a buildup of material occurs in this area.

The method used to reduce the stress riser was to make some of the windings extend beyond the PT's, other windings terminated at the PT's, with the balance of the windings inside the PT's. The following sketch illustrates the mothod which was used to provide a circumferential wrap. (See Figure 4-2.)

On all circumferential wraps (not longitudinal wraps), one (1) 375-watt infrared heat lamp was used during wrapping. The heat source was maintained approximately one-half (1/2) inch above the contact point between the circumferential tape and the mandrel.

LONGITUDINAL WINDINGS

The application of longitudinal material to the winding arbor, with automated equipment, is relatively simple. The starting end of the tape is attached to the mandrel with a pressure sensitive tape, such as mylar. This starting end is crossed over after a few cycles and the hold-down tape can then be removed. The excess length of the starting end is then trimmed to the point of crossover. Upon completion of the winding, the tape is terminated with an overlap of a least 3 inches into the next generation. (See Figure 4-3) One continuous length of material should be used for a longitudinal generation (two layers).

END DOME REINFORCEMENTS

One method, regularly used for adding reinforcements in the end dome, is to use woven glass cloth. It is most difficult to program this type of material on a curved surface and iron out the wrinkles. A desirable method of dome reinforcement would make use of the same materials which form the cylindrical and longitudinal windings. A method has been worked out to use the same pre-preg materials and apply them to the arbor with the regular winding equipment.

Essentially, this method consists of winding an extra longitudinal generation and removing the material from the unwanted areas. The simplest means of adding a full dome reinforcement is the placing of a thin stainless steel strip two inches in width around the cylindrical section near the PT's. The added generation

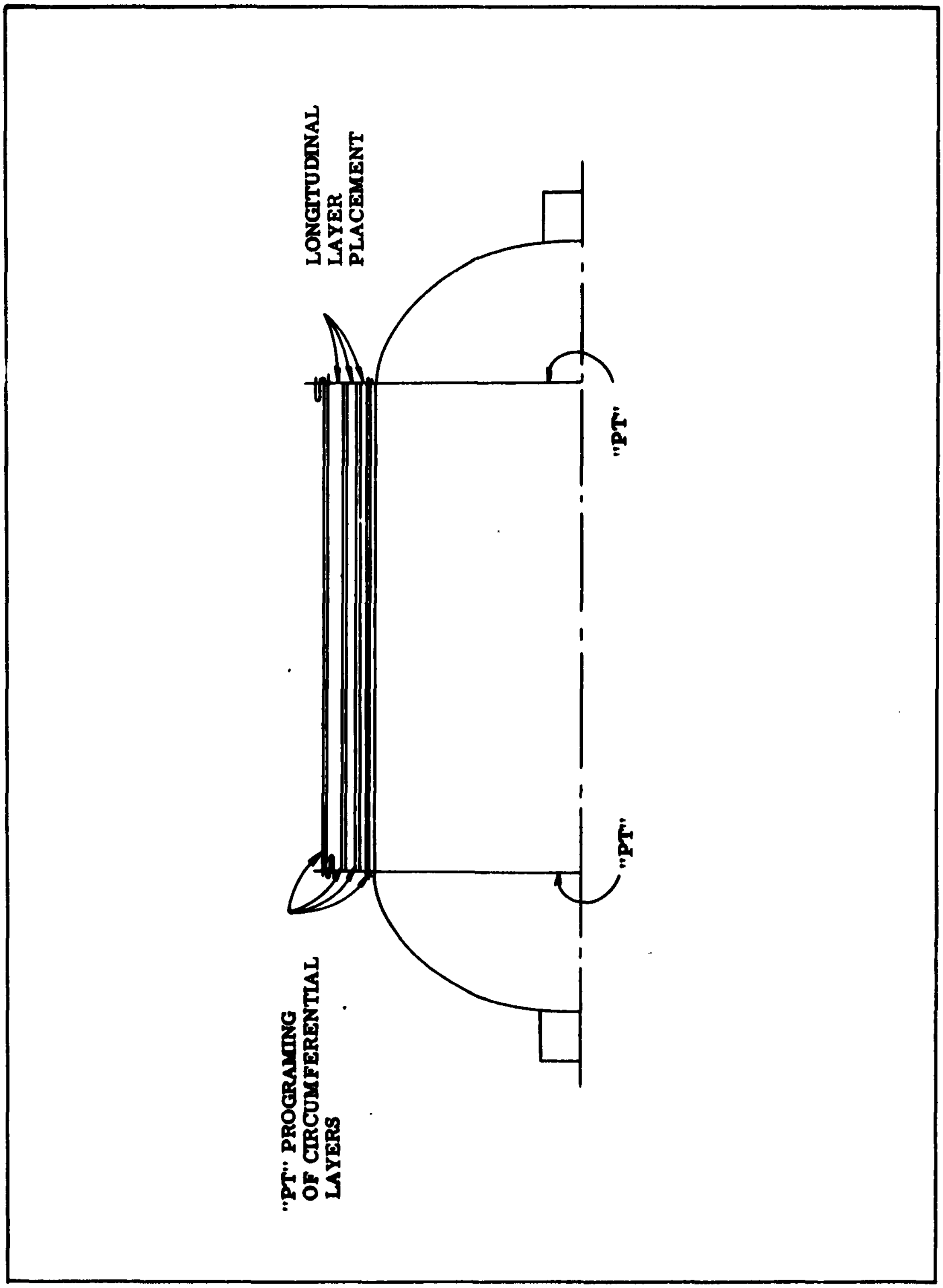


Figure 4-2. Location of Circumferential Layer Placement and Termination

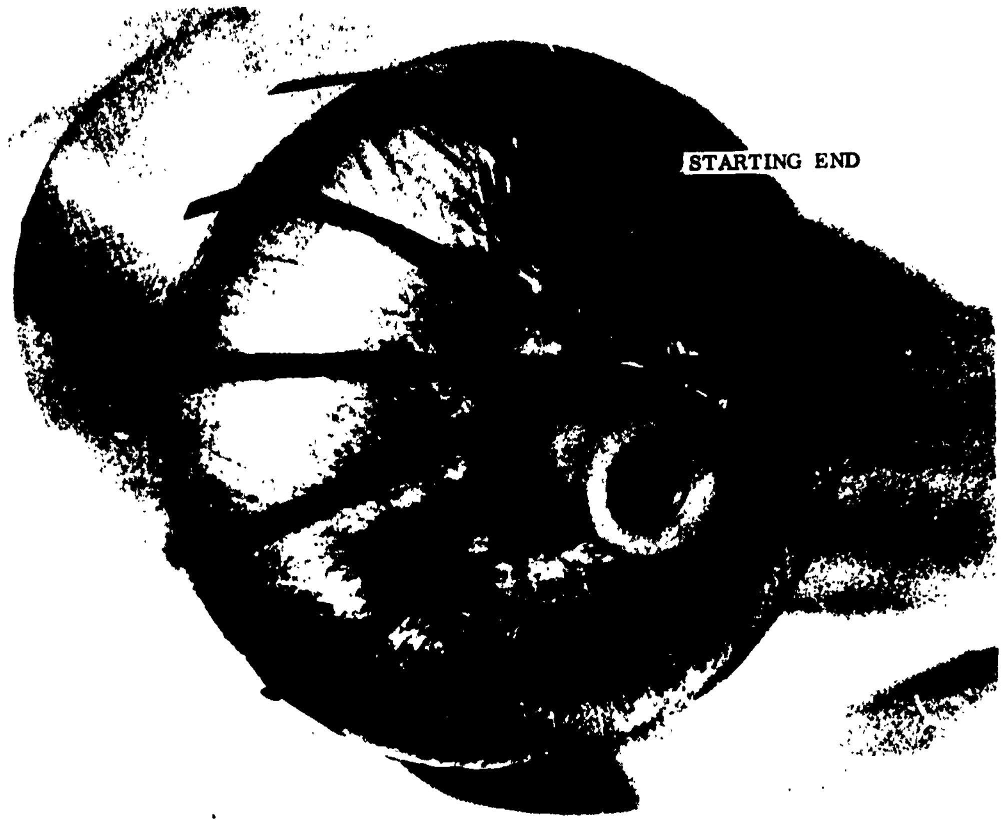


Figure 4-3. Termination of Longitudinal Tape Ends

is then applied over this strip and the glass tapes are cut through to the underlying bands. With most pre-pregs the unwanted windings in the cylindrical section can be removed without damage to the underlying wraps. Do not use more winding tension than necessary to adequately seat the material in the end dome region. When the tension is released by the cutting action, the tape ends have a tendency to ruffle. A winding tension of 0.2 pounds per end with ECG-140 glass filaments has been found satisfactory.

SPECIAL APPLICATIONS

In a design which has two longitudinal generations (4 layers), a full reinforcement may be added between the two longitudinal wraps. When working with a design that contains three longitudinal generations, it is desirable to divide the reinforcements into two parts and place them between the first and second, and second and third longitudinal wraps. This can be provided for with most wrap patterns. When numerical controlled machinery is used, the process is relatively simple.

The type of wrap pattern used during this program was well adapted for the task. Reducing the number of spaces in the grid pattern from 103 (which is a normal wrap pattern solution) to 102 spaces gives a complete longitudinal generation after 51 cycles. This places tape in every other space of the 102-space grid.

The process consists of applying the first 102-space wrap to the arbor on top of the first longitudinal generation (103 spaces) (2 layers) and then removing material from the unwanted areas. After applying the second longitudinal generation (103 spaces), apply the second application of tape with the 102-space pattern. It is necessary that the second application be indexed over one space to fill the void spaces from the first application. This provides a 100% end dome generation coverage which has been fabricated between different layers of the case structure.

SECTION V

SEVEN INCH DIAMETER PRESSURE VESSELS

DESCRIPTION OF "BASIC" PRESSURE VESSEL

The physical size of the pressure vessel was 7. 170" I. D. with a cylindrical length of 8. 5" and IDEAL END DOMES. (See Figure 5-1 for further details.) The construction was such that the longitudinal and girth windings were intermixed. A polar opening diameter was selected to provide a 12. 5° helix angle of the longitudinal windings in the cylindrical section. Generally, the case circumference in inches, divided by the longitudinal material band width per pass, is in a range from 90 to 130. A value of 103 was used for this design because it provided for using two 20 end pre-preg rovings in parallel and also provided a geodesic solution for a type of wrap pattern found most desirable in an Air Force sponsored contract. Also, this design was equally desirable for use with pre-preg tapes.

DERIVATION OF IDEAL END DOME

The end dome contour utilized in this program was in the same basic contour used in the Air Force contract. The contour was "ideal" for a 12. 5° longitudinal wrap angle. The contour was derived analytically and checked experimentally prior to the start of these contracts. The analytical work was based on the consideration that the filaments are the members which carry the internal pressure loads and should be orientated to create an isotensoid structure, providing uniform load distribution to all elements. A pressure vessel was then fabricated which incorporated the above parameters and checked experimentally by the "pressure cure method." Pressure curing is maintaining an internal pressure during the resin cure cycle. The conditions which exist are that the winding arbor has been removed and the case is under internal pressure. This cure method requires that the chamber must have been wrapped on a soluble mandrel covered with a pressure tight bladder. The end fittings were sealed to the bladder and the shaft sealed to the end fittings. The case was wrapped with no loose ends. The beginning and end of the tape were tied to the pole fitting or to an opposing tape to preclude "unwind" during cure. The resin becomes very fluid during one stage of the cure and is unable to carry any shear force; in reality, the filaments are lubricated and are free to move with respect to each other. Therefore, they will take a position where they are under the least stress in accordance with the principles of conservation of energy, least work, etc. The resulting end dome contour is ideal—that associated with least filament stress—and will carry the greatest pressure before failure.

Two results are determined from pressure curing: The proper end dome contour, and the points of tangency of the chamber.

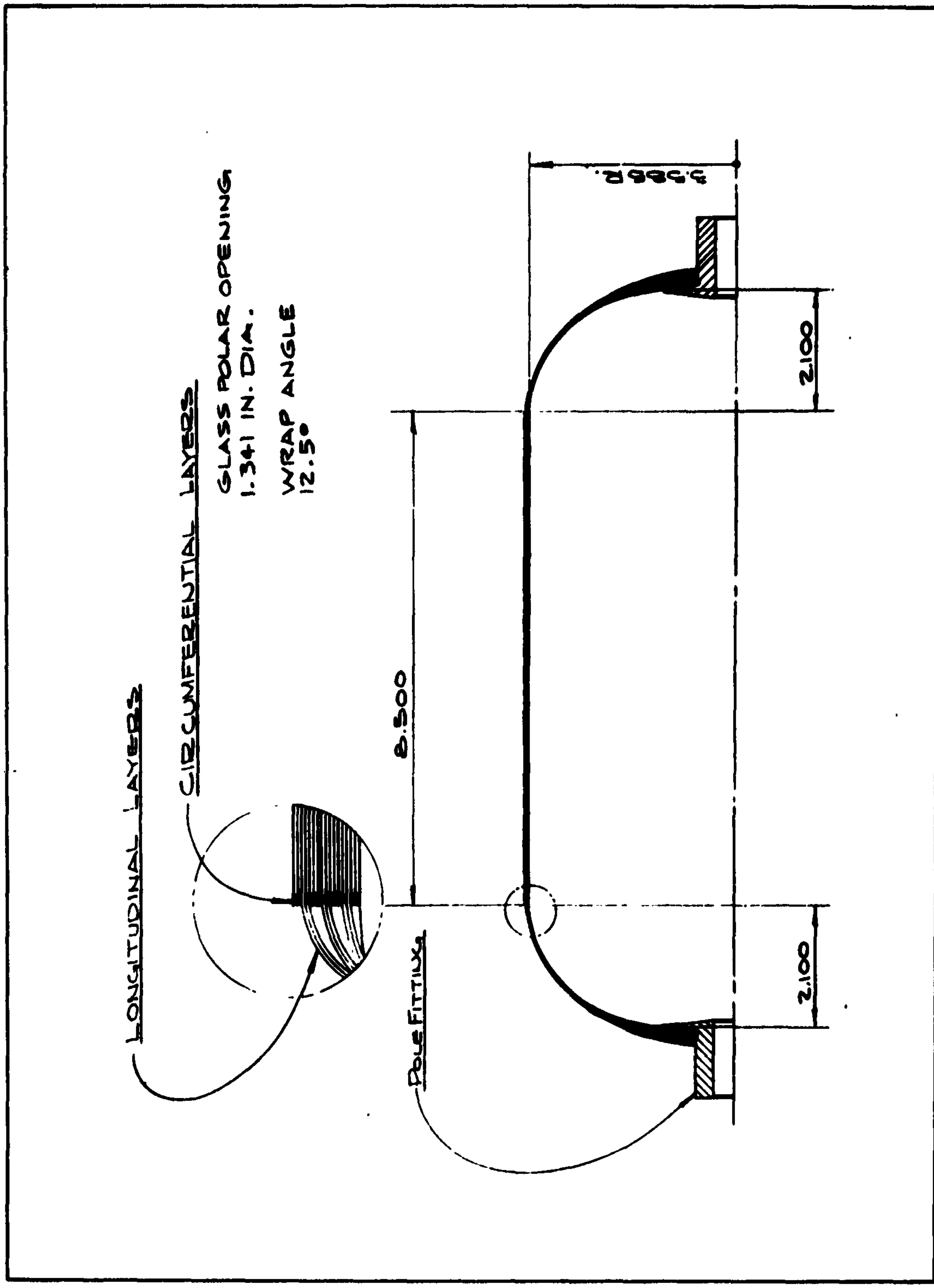


Figure 5-1. Basic Pressure Vessel

Figure 5-2 shows a glass filament case having the mandrel washed out under pressure as part of the processing of pressure curing.

Description of Wrap Pattern

This wrap pattern divides the circumference into 103 spaces and requires 103 cycles to complete the generation. This provides two (2) thicknesses of material in the cylindrical section (assuming the tape width is equal to the space width).

The longitudinal winding pattern is such that the location of the tape at the start of a cycle indexes over eight (8) spaces from the start of the preceding cycle. Therefore, the tape of the thirteenth (13th) cycle lies adjacent to the tape of the first (1st) cycle, and the tape of the fourteenth (14th) cycle lies adjacent to the tape of the second (2nd) cycle, etc. One hundred three (103) cycles complete the tape requirements for the longitudinal generation. The one hundred fourth (104th) cycle would place another tape over the tape of the first cycle.

SUMMARY - SEVEN INCH DIAMETER CASES

The selection of materials for use in the test pressure vessels was based on the results of the Phase I activities (see Report No. BAE-863-14367). The materials were of two basic categories, tapes and rovings. The roving was 20 end pre-preg with 801 sizing and 16 to 20 per cent resin content (by weight) and manufactured by the Cordo Chemical Company.

The tape was made from yarns which were laid parallel, without crossovers, of uniform width and thickness, and all ends of uniform length. The yarn was ECDE-300-1/0-1.0 T. P. I. with EPS-4 sizing. An average tape cross section had approximately 216 yarn ends per inch of width. The tape was fabricated by BENDIX. Resin content was from 16 to 20 per cent by weight.

Results

A. Comparison of stress values obtained for tape and roving from identical designs were of the same order of magnitude (SPN-01 versus SPN-02) (SPN-05 versus SPN-06) (SPN-03 versus SPN-07)(SPN-04 versus SPN-09).

B. The tape material compacted better than roving in both the cylindrical and end dome regions. This was due to the more uniform control of width and thickness of tape as compared to roving.

C. A balanced designed isotensoid geodesically wrapped pressure vessel (12.5° degree longitudinal wrap angle) is weakest in the longitudinal winding at the point of tangency.

D. The highest stress values were obtained in the design used for the consistency checks (SPN-12, 15, and 16).

Circumferential Glass Stress . . . 334,761 psi
Longitudinal Glass Stress. . . . . 235,769 psi
Strength-weight Ratio . . . 1.704 x 10^6 inches

E. End dome reinforcements should extend a minimum of 3/4 inches into the cylindrical section

ENGINEERING DISCUSSION

Due to the desirability of obtaining the highest S/W, every effort is made to achieve the maximum filament strength with the minimum resin content. Ultimate filament strengths are still achieved with resin contents (by weight) of less than 20% in "D" ring tests.

Test data shows that in actual performance the pressure vessel imposes added requirements on the pre-preg filament system.

Figures 5-9 and 5-10 are examples of the desirability of having different resin contents in different sections of the structure. These two cases, which were built prior to this contract, are identical to the cases being used in this program. Both cases were built from the same pre-preg 20 end roving with 19-1/2 per cent resin content. The case in Figure 5-9 which failed at 2210 psi, had extra resin added around both center port openings. The failure was at the point of tangency. In order to prove the necessity of adding resin in this location, the case shown in Figure 5-10 was built identical to the case in Figure 5-9 except - "NO ADDED RESIN."

It was evident from appearance of the structure in the pole region that there were voids caused by the normal interweaving of material during wrapping. The case failed at 1850 psi at the pole fitting. Extra resin would be required to provide a void-free structure.

Figure 5-6 shows the first case, SPN-01, being hydro-tested. The case was suspended from the top center port and the lower fitting was unrestrained. The photo, Figure 5-6, is a double exposure taken at 0 and 1,000 psi. Note the uniform expansion and balanced deflection.

Figure 5-11 shows case No. SPN-07 which has the end dome reinforcement extending into the cylinderical section 1/4 inch. Note that the origin of failure was at the termination of the dome reinforcement.

Figure 5-12 shows case No. SPN-15 which has the end dome reinforcement extending into the cylinderical section 3/4 inch. The origin of failure appears to have been in the circumferential windings at approximately one (1) inch from the P. T.

IMPROVED PRE-PREGS

Which is more desirable, yarn or roving to form pre-preg tapes? A glass tape is defined as a number of ends (204 monofilaments/end) which are parallel, without crossovers, of uniform width and thickness, and all ends of uniform length. Rovings available

(continued on page 5-16)

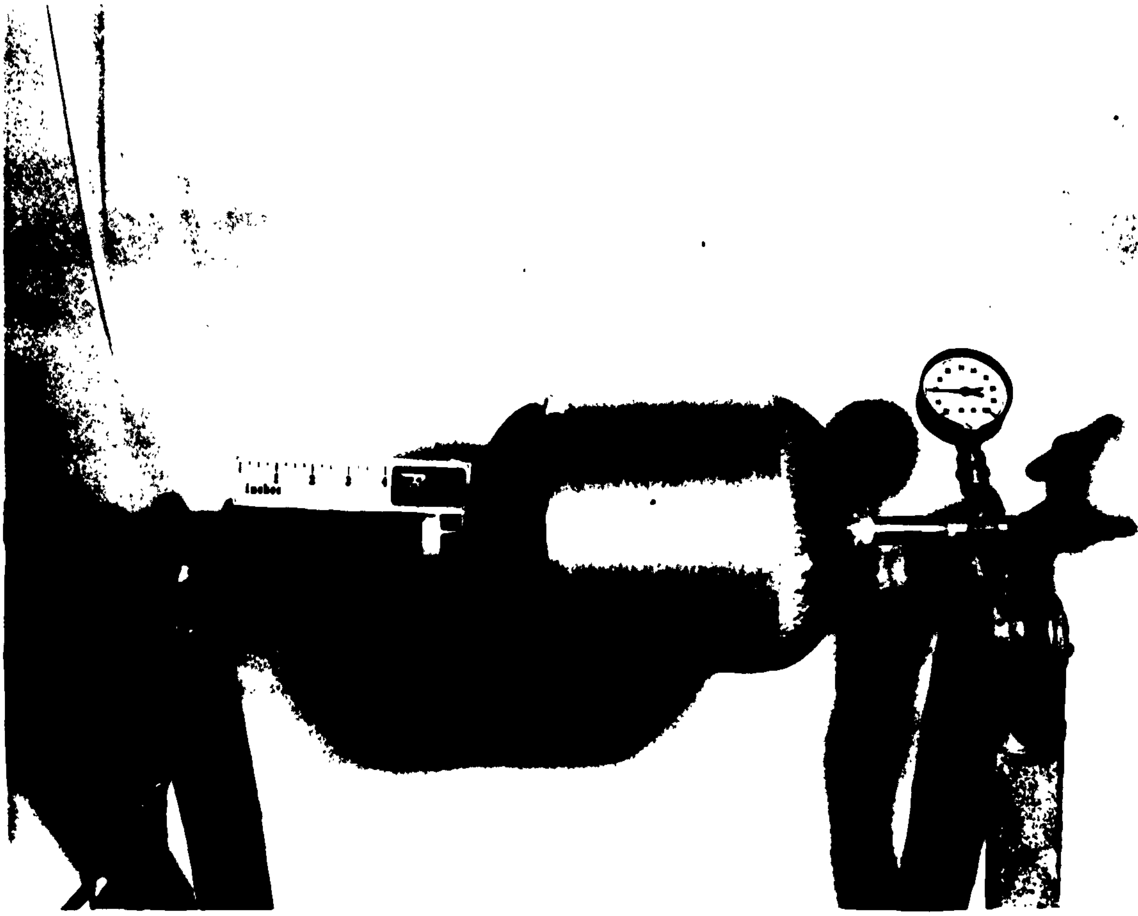


Figure 5-2. Fiberglass Case With The Mandrel Being Washed Out Under Pressure (Note - The Resin Is Not Cured)

	SPN-01	SPN-02	SPN-03	SPN-04	SPN-05	SPN-06	SPN-07	SPN-08	SPN-09	SPN-10	SPN-11	SPN-12	SPN-13	SPN-14	SPN-15	SPN-16
Mat'l	ECDE-300 1 0 1 0 T.P.I.	ECG-140 20 ends	ECDE-300 1 0 1 0 T.P.I.	ECDE-300 1 0 1 0 T.P.I.	ECDE-300 1 0 1 0 T.P.I	ECG-140 20 ends	ECG-140 20 ends	ECDE-300 1 0 1.0 T.P.I.	ECG-140 20 ends	ECG-140 20 ends	ECG-140 20 ends	ECDE-300 1 0 1 0 T.P.I.	ECDE-300 1 0 1.0 T.P.I.	ECDE-300 1 0 1.0 T.P.I.	ECDE-300 1 0 1.0 T.P.I	ECDE-300 1 0 1.0 T.P.I
Size	EPS-4	801	EPS-4	EPS-4	EPS-4	801	801	EPS-4	801	801	801	EPS-4	EPS-4	EPS-4	EPS-4	EPS-4
Tape or Roving	Tape 46 ends 213 wide	Roving 20 ends approx 106 wide	Tape 46 ends 213 wide	Tape 46 ends 213 wide	Tape 46 ends .213 wide	Roving 20 ends approx 106 wide	Roving 20 ends approx. 106 wide	Tape 46 ends .213 wide	Roving 20 ends approx 106 wide	Roving 20 ends approx. .106 wide	Roving 20 ends approx. 106 wide	Tape 46 ends .213 wide	Tape 46 ends .213 wide	Tape 46 ends .213 wide	Tape 46 ends .213 wide	Tape 46 ends .213 wide
% Resin by Weight	18 3	15 42	18 71	17 57	20 35	19 95	16.48	17 10	18.41	18.742	16.5	22.3	19.8	21.6	20.486	21.3
Winding Tension	15# per tape (46 ends)	9# Roving (20 ends)	15# Tape (46 ends)	15# Tape (46 ends)	15# Tape (46 ends)	9# Roving (20 ends)	9# Roving (20 ends)	15# Tape(L) 35# Tape(C) (46 ends)	9# Roving (20 ends)	9# Roving (20 ends)	9# Roving (20 ends)	15# Tape(L) 35# Tape(C) (46 ends)	15# Tape (46 ends)	15# Tape (46 ends)	15# Tape(L) 35# Tape(C) (46 ends)	15# Tape(L) 35# Tape(C) (46 ends)
Construction in Layers	10 circ 6 long	7 circ 4 long	10 circ 6 long	10 circ 5 long	6 circ 6 long	4 circ 4 long	7 circ. 4 long	8 circ 6 long	7 circ. 4 long	4 circ. 4 long	4 circ 4 long	8 circ. 6 long	8 circ. 6 long	8 circ 6 long	8 circ 6 long	8 circ. 6 long
Ultimate Test Pressure	1500 psi	2040 psi	1355 psi	1550 psi	965 psi	1150 psi	2040 psi	1195 psi	1645 psi	1480 psi	Bending 6400#	1600 psi	Bending	1280 psi	1645 psi	1345 psi
Weight of glass and Resin	931#	1 27#	1 22#	1 136#	886#	1 095#	1 548#	960#	1 612#	1.066#	- -	941#	- -	1.042#	1.039#	1.064#
Stress in Glass	circ 258 000 long 227 000	circ 245 300 long 226 700	circ 233 000 long 204 000	circ 257 500 long 226 300	circ 266 000 long 145.500	circ 228.000 long 120 500	circ. 237.000 long. 220.000	circ 245.000 long. 172.800	circ 189.000 long 174.000	circ 296.000 long. 156.000	-	circ. 324.000 long. 228.300	-	circ 366.000 long. 187.400	circ 334 761 long. 235.769	circ. 274.000 long. 193.000
Foreword end Reinf. Doily)	None	None	1 4' Past "Pt"	3 4"Past "Pt"	None	None	1 4"Past "Pt"	3 4"Past "Pt"	3 4"Past "Pt"	None	None	3 4"Past "Pt"	None	3 4"Past "Pt"	3 4"Past "Pt"	3 4"Past "Pt"
Aft end Reinf (Doily)	None	None	1 4"Past "Pt"	3 4"Past "Pt"	None	None	1 4"Past "Pt"	3 4"Past "Pt"	3 4"Past "Pt"	None	None	3 4"Past "Pt"	None	3 4"Past "Pt"	3 4"Past "Pt"	3 4"Past "Pt"
Strength to weight in cyl 10^6 ins	1 485	1 485	1 330	1.487	1.189	1.020	1.415	1.320	1.105	1.345	- -	1.610	- -	1.337	1.704	1.380
Location of Failure	End dome approx 15° up from "Pt"	End dome at the "Pt"	At termin of end dome reinf.	End dome at "Pt"	Circ at "Pt"	Circ at "Pt"	At termin. of end dome reinf.	Circ. between "Pts"	End dome at pole fitting	Circ. Failure	Center of Cylinder Section	One inch from "Pt" in circ. Section		One inch from "Pt" in circ. Section	One inch from "Pt" in circ. Section	One inch from "Pt" in circ. Section

Figure 5-3. Summary of Seven Inch Test Cases - SPN Program

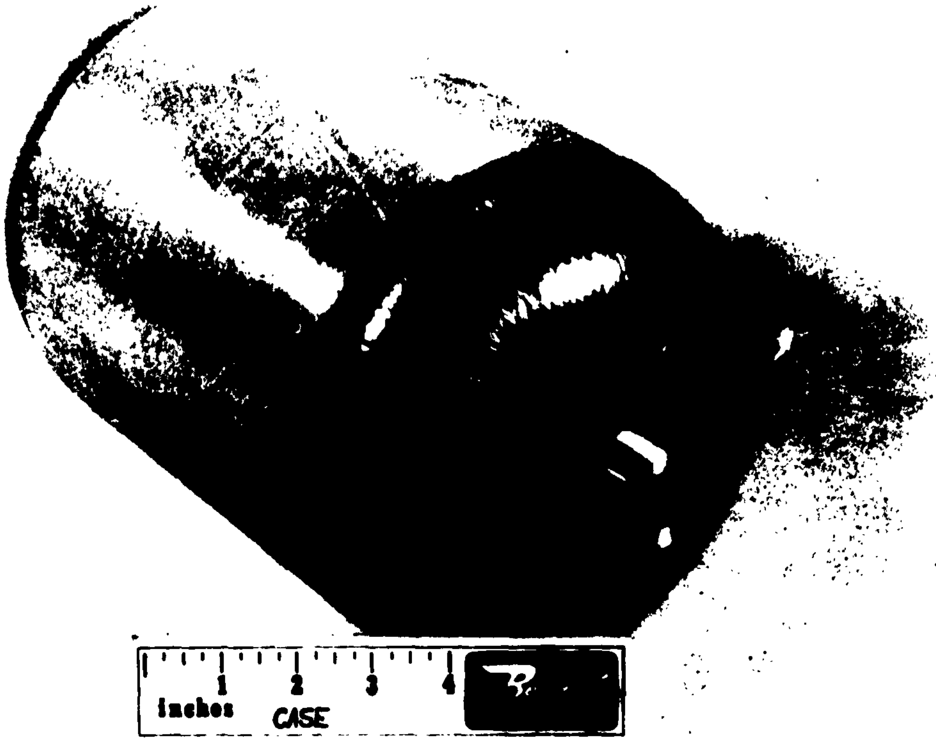


Figure 5-4. Test Case SPN-01 Before Test

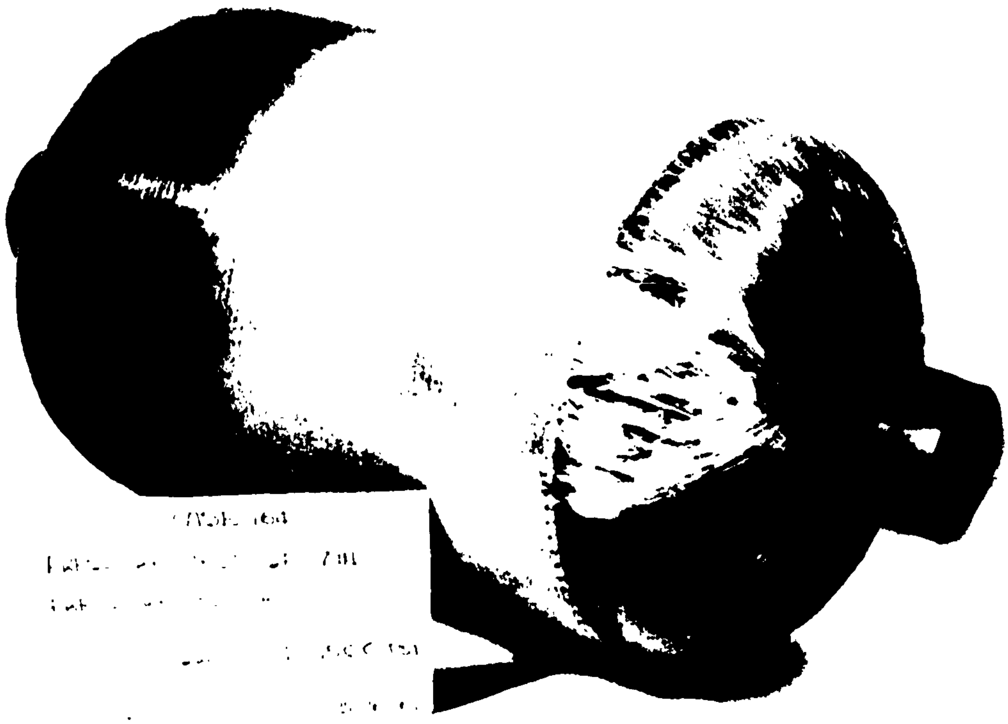


Figure 5-5. Test Case SPN-01 After Test

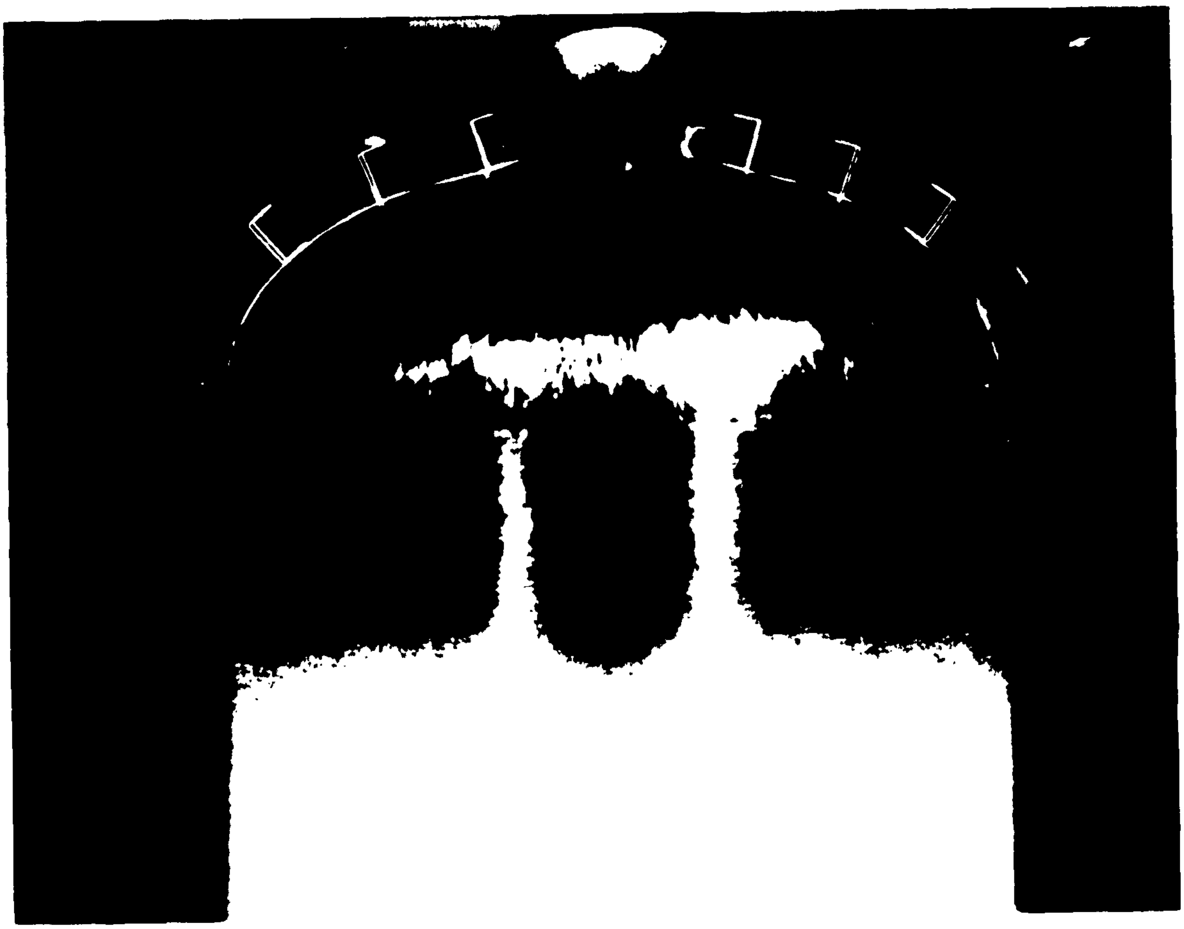


Figure 5-6. Double Exposure Hydro Test SPN-01 at 0 and 1,000 psi

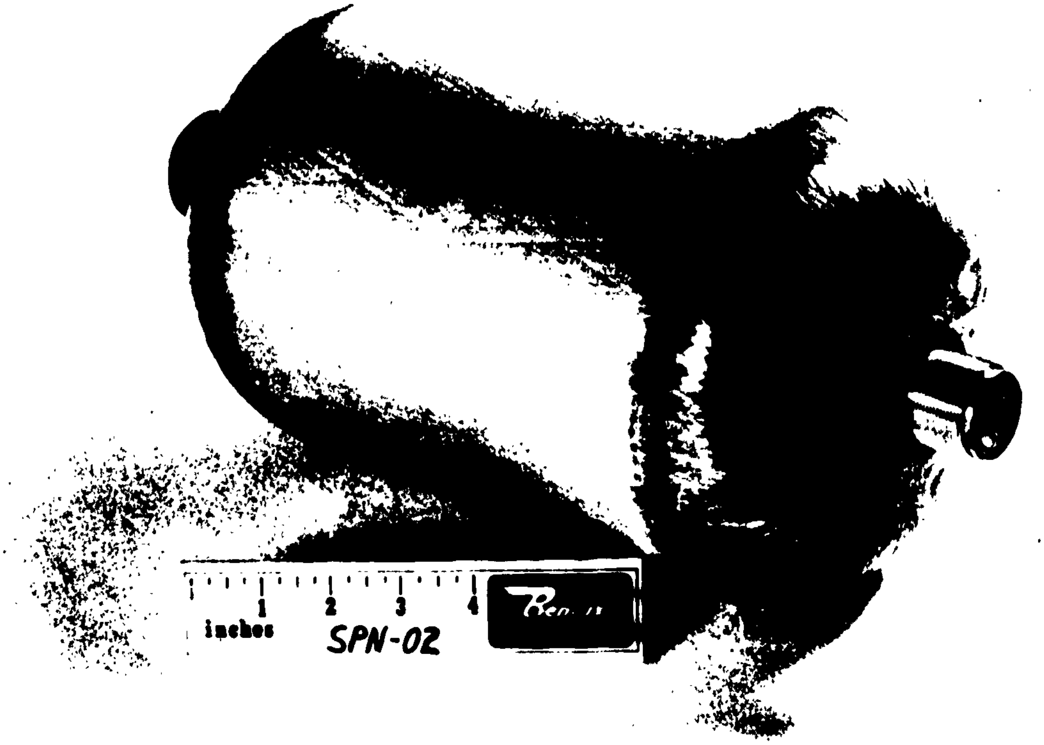


Figure 5-7. Test Case SPN-02 Before Test

Figure 5-8. Test Case SPN-02 After Test

Figure 5-9. Test Case With Added Resin

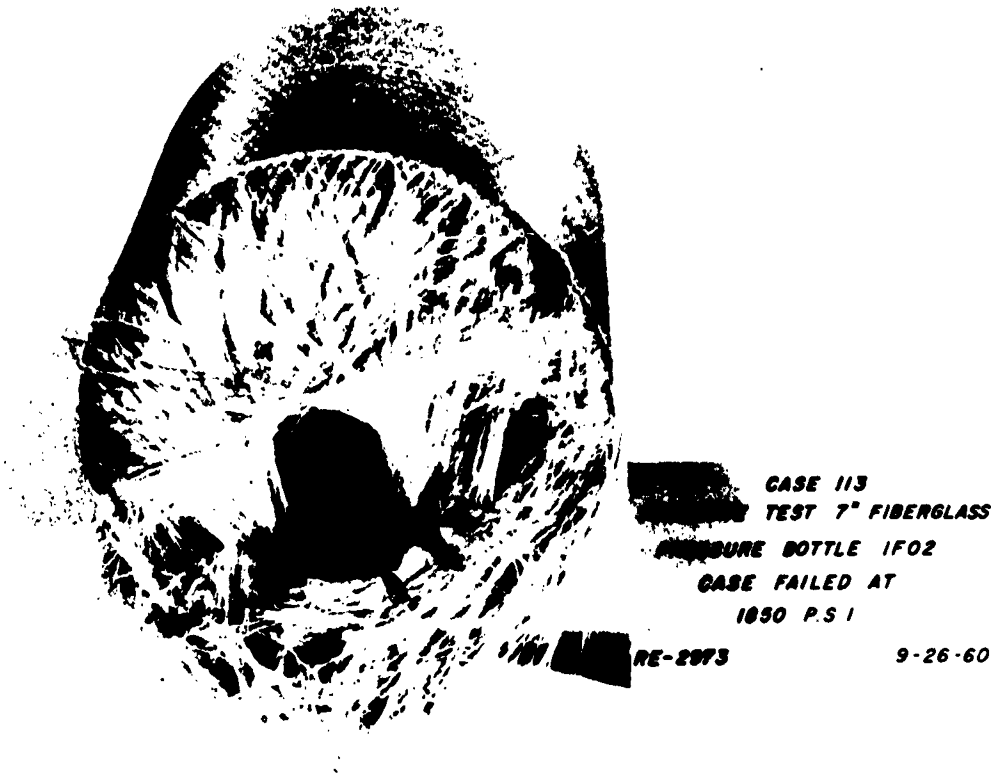


Figure 5-10. Test Case Without Added Resin

Figure 5-11. Test Case SPN-07

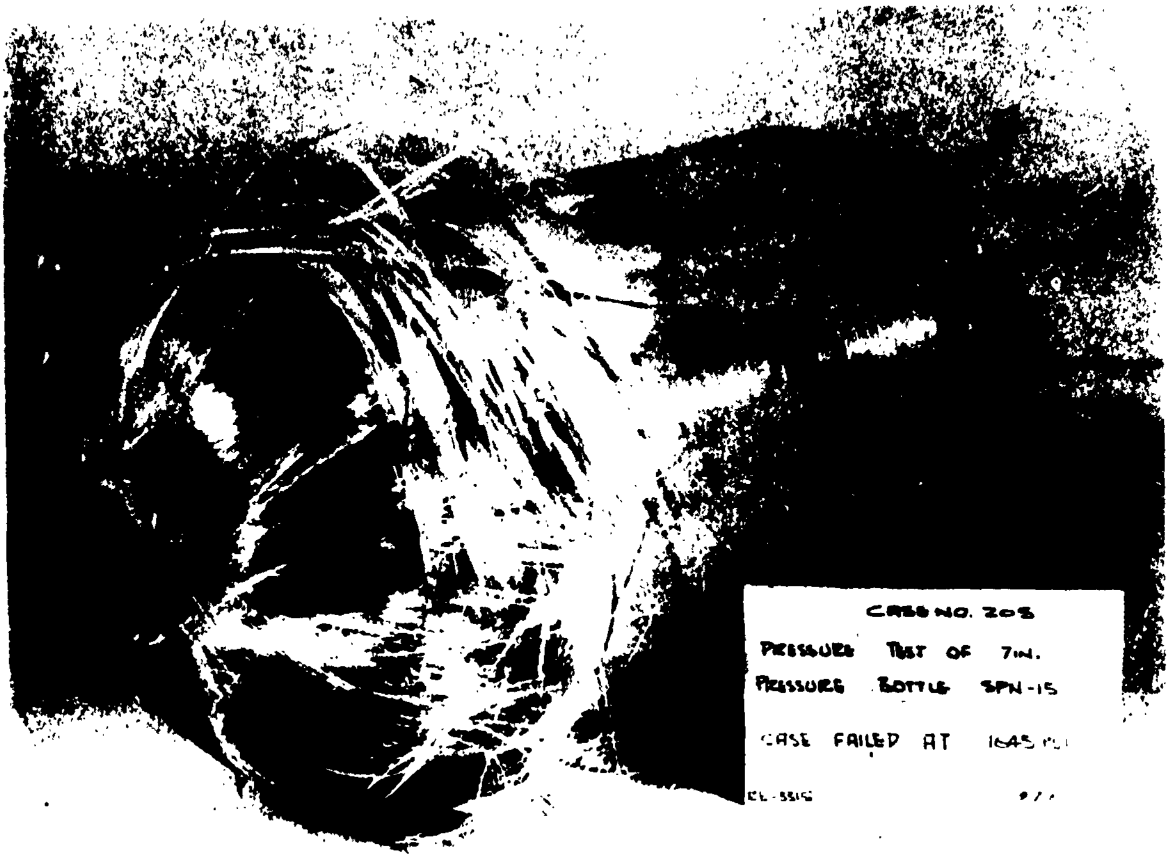


Figure 5-12. Test Case SPN-15

to date do not meet these specifications.

Yarn will meet the above requirements to form a tape, however the added processing at the glass mill to form a "yarn" from the forming tube results in some damage to the glass. Actually, the desirable quality of a yarn is that a single end of glass is available for processing in the tape forming machine.

RECOMMENDATIONS

An improved tape with more reliability could be manufactured by processing directly from the forming tube into the tape forming machine.

FILAMENT DIAMETER

The tape used for fabrication of pressure bottles was made from EC DE-300-1/0-1.0 T.P.I yarn. The yarn contained 204 monofilaments of 0.00025 inch diameter. The cross sectional area of "DE" filament is approximately one-half that of a "G" filament normally used in filament winding.

Although the fiber diameter does not significantly affect the strength of the filaments and strands themselves, greater fineness allows greater dispersion of the structural elements in the resin and therefore reduces the probability of fault propagation.

Probably the most significant use of filaments finer than "G" size could be for added reinforcements wherein reduction of stress risers is usually of prime importance.

SECTION VI

EIGHTEEN INCH DIAMETER PORTED CASES

The 18 inch diameter cases were in the program to ascertain the effect of scaling from 7 inch diameter to 18 inch diameter cases. It was not practical to investigate off center port reinforcements in small size cases. An 18 inch case is sufficient to investigate multi-port reinforcements. The two 18 inch cases fabricated and tested were exact scale ups of the 7 inch cases used for the consistency tests and the port reinforcements were made with pre-preg tapes programed tangent to the nozzle openings.

It was planned to incorporate the nozzle openings into the aft end dome without disturbing the scaling effects or methods of reducing stress concentrations. The two cases were to differ only in the amount of nozzle reinforcement material. It was planned to program sufficient nozzle reinforcement material into the first case so that it would not fail in the aft dome region. The second case was modified, based on test results, to fail through the nozzle port openings.

SUMMARY OF RESULTS

Both of the 18 inch diameter cases failed as planned. The first case failed in the cylindrical section at a stress level comparable to that obtained in the 7 inch diameter program. The effect of scaling up and methods of reducing stress concentrations worked as well in the 18 inch diameter cases as in smaller size hardware. The second case had 50 per cent less reinforcement material in the immediate area of the nozzle opening. Based on the test data from the first case, the nozzle reinforcement was designed to fail at approximately 450 psi. The second case failed as predicted at a pressure of 442 psi. See Figure 6-1 for general construction details.

Hydrotest Results

The failure was in the circumferential section at 592 psi, see Figures 6-2 and 6-3.

Circumferential glass stress	320,000 psi
Longitudinal glass stress	221,000 psi

Strength to weight ratio in cylindrical section (This includes glass plus resin weight) 1.585×10^6 inches.

The second case failed through the nozzle port opening at 442 psi. The strength of this nozzle port reinforcement was (442/592) 75 per cent as strong as the case side wall. See Figure 6-4. (text continued on page 6-6)

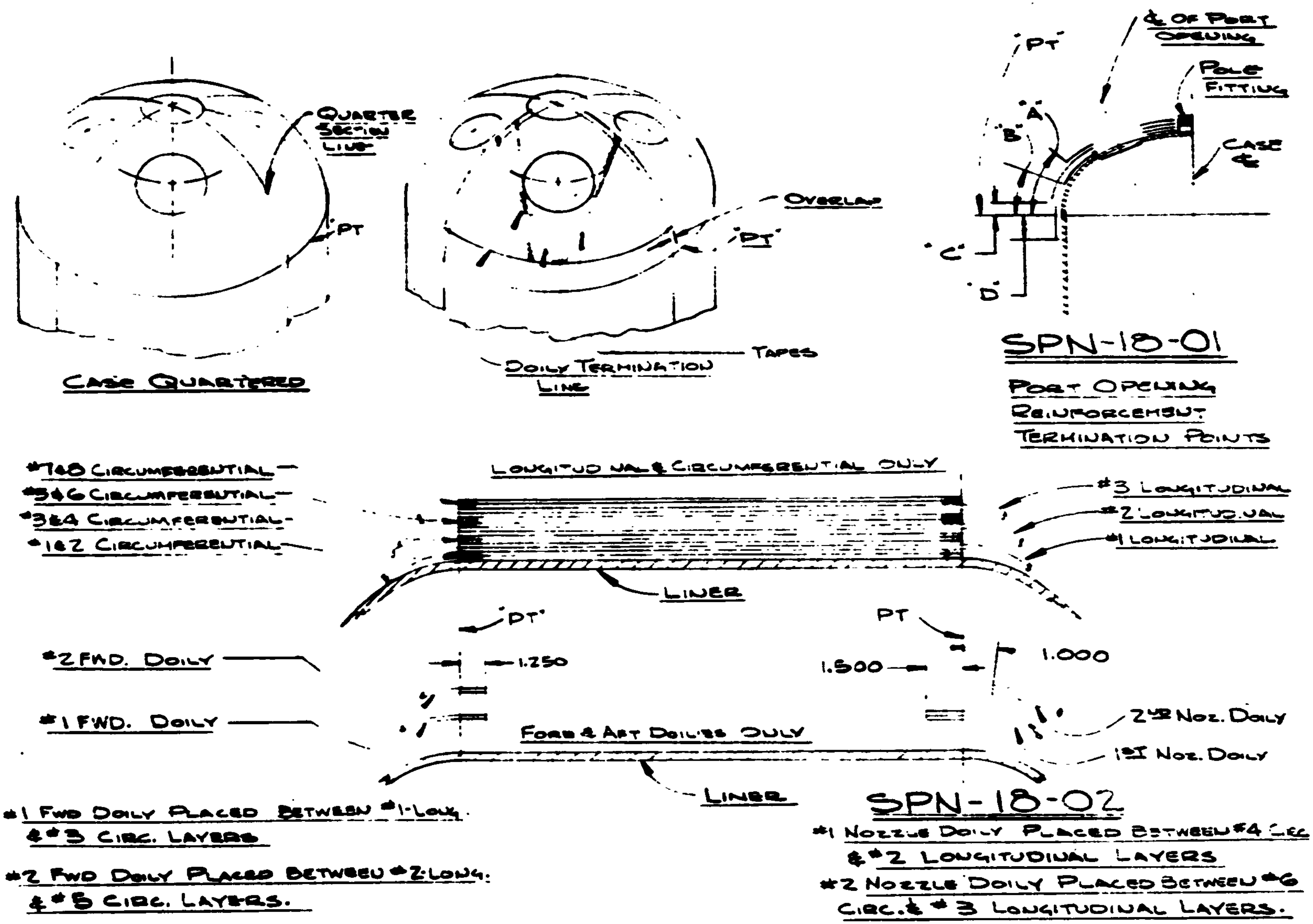


Figure 6-1. Construction Details For Cases SPN-18-01 And SPN-18-02

Figure 6-2. Burst Side Of Test Case

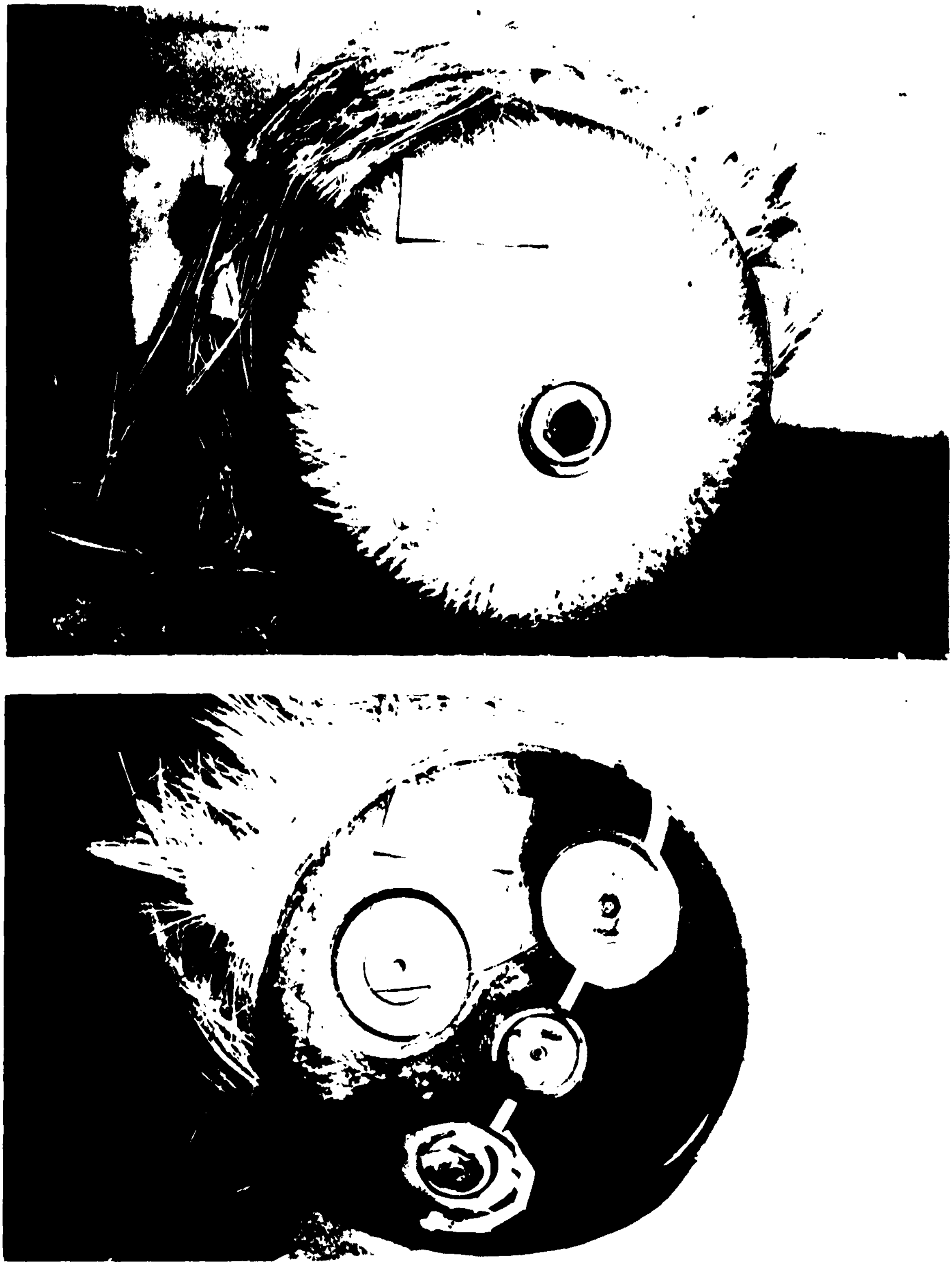


Figure 6-3. End Dome Sections After Burst Test

Figure 6-4. Test Case SPN-18-02 After Test

Nozzle port rotations for both cases are in the order of 3/4 of 1 degree.

OFF-CENTER PORT REINFORCEMENTS

One of the most critical problems with filament wound cases is nozzle port rotation during pressurization. Part of this difficulty arises from non-uniform placement of reinforcement material at nozzle port openings. When reinforcements are pre-fabricated in a plane, laid on the arbor and forced to conform to the dome contour, the material is no longer in a uniform and precise pattern.

The method of off-center port reinforcement described herein provides for a precise placement of material which will not be disturbed when placed on the winding arbor. The construction of the reinforcement is symmetrical about a plane which passes through the longitudinal axis of the case and through the center of the nozzle port opening. Thus the deflection of the end dome with respect to this plane will be balanced. End dome deflections about a plane at 90 degrees to the plane of symmetry may not be balanced; however, these deflections can be balanced by proper programming of the material.

DESIGN CONCEPT OF REINFORCEMENTS

The method adopted for reinforcing off-center port openings consists of fabricating the longitudinal windings with the exact winding pattern as was used in a plain pressure bottle and adding material around the location where the port opening is to be incorporated. After curing, the desired area is opened by cutting out the filaments of the basic pressure vessel which lay over the intended opening. However, none of the reinforcing material added around the opening is cut; thus, undisturbed filaments are provided to carry the loads around the opening.

A brief explanation of the basic principles arrived at during the development of this type reinforcement will clarify the design used. This "doily" type reinforcement provides distribution of material around the hole opening which is the same as that created at on-center ports in a regular winding pattern. This is the natural method of locating filament material around an opening wherein the material adjacent to the opening is in tension. The load is maximum at the edge of the hole and diminishes very rapidly away from the opening. The resulting physical tapered cross section through the off center port reinforcement lay up shows the desired fairing. (See Figure 6-5)

The PROBLEM is how to fair the edges of the doily reinforcements where they contact each other between two adjacent ports and at their extremities toward the PT line of the case.

The method used to layout a doily is to use a full scale model of the end dome and locate the centerlines of the pole piece and the off center port openings. Next, scribe on the diameters of the off center port openings and diameter of pole piece.

> NOTE: To accurately determine the location of tapes in a reinforcement, it is necessary to work from the actual full scale (true) contour. The most important item in the design is to fair out the tape ends toward the PT line of

Figure 6-5. Center Port Reinforcement Lay-up

the case. To provide sufficient strength at the hole opening with this design is not the primary problem. It might appear, on first glance, to be somewhat of a "blacksmith approach" to design from the model concept in lieu of a mathematical and descriptive geometry approach. The strict mathematical approach requires the exact geodesic path of all curves tangent to the hole opening. In addition, the curves must be reduced to tables of x, y, and z coordinates. It is then apparent that the model and layout method is a sound engineering approach.

The outer extremities of the doilies must be defined and located. The end dome is divided into four (4) equal segments with the center of an off-center port opening being the focal point for each doily design. The ends of the doily should terminate on lines parallel to the PT. The side next to the on-center port can extend to the polar opening diameter used for longitudinal winding. The side next to the PT will vary in distance from the PT depending on the intended location of the doily during winding. Next, scribe a line which extends from the center of the pole piece through the center of the off-center port to PT. The doily design should be symmetrical about this line. Extend 72 radial lines from the center of the nozzle opening to divide the circumference of the nozzle opening into equal arc lengths. A doily is started by placing a length of tape tangent to one of the radial lines at the hole opening. Extend the tape along a geodesic path, away from the port opening, and terminate the ends at the outer extremities designated for the doily. Repeat this process for each of the radial lines. (See Figure 6-6)

Examine the pattern at the outer extremities for uniformity of spacing. Revise the spacing at the outer extremities for more uniform spacing, or as defined from an analytical approach to reduce stress concentrations. The angular location of the radial lines controls the spacing of the tapes at the outer extremities of the doily. Therefore revise the angular locations of the radial lines as required.

Compare the load carrying capacity of the doily at the nozzle port opening with the loads predicted to be present by mathematical analysis. The number of doilies per opening can be the same as the number of longitudinal windings. After selecting the desired number of doilies, material will probably be added or subtracted to meet the load requirements. Be very careful not to induce stress risers on the end next to the PT during the revision process. (See Figure 6-7.) For complete details of reinforcement used, see Monthly Progress Reports No. 9, for Period of Nov. 1 - Nov. 30, 1961 (BPD-863-14317), and No. 10 for Period of Dec. 1 - Dec. 30, 1961 (BPD-863-14340).

Figure 6-6. Dolly Lay-up

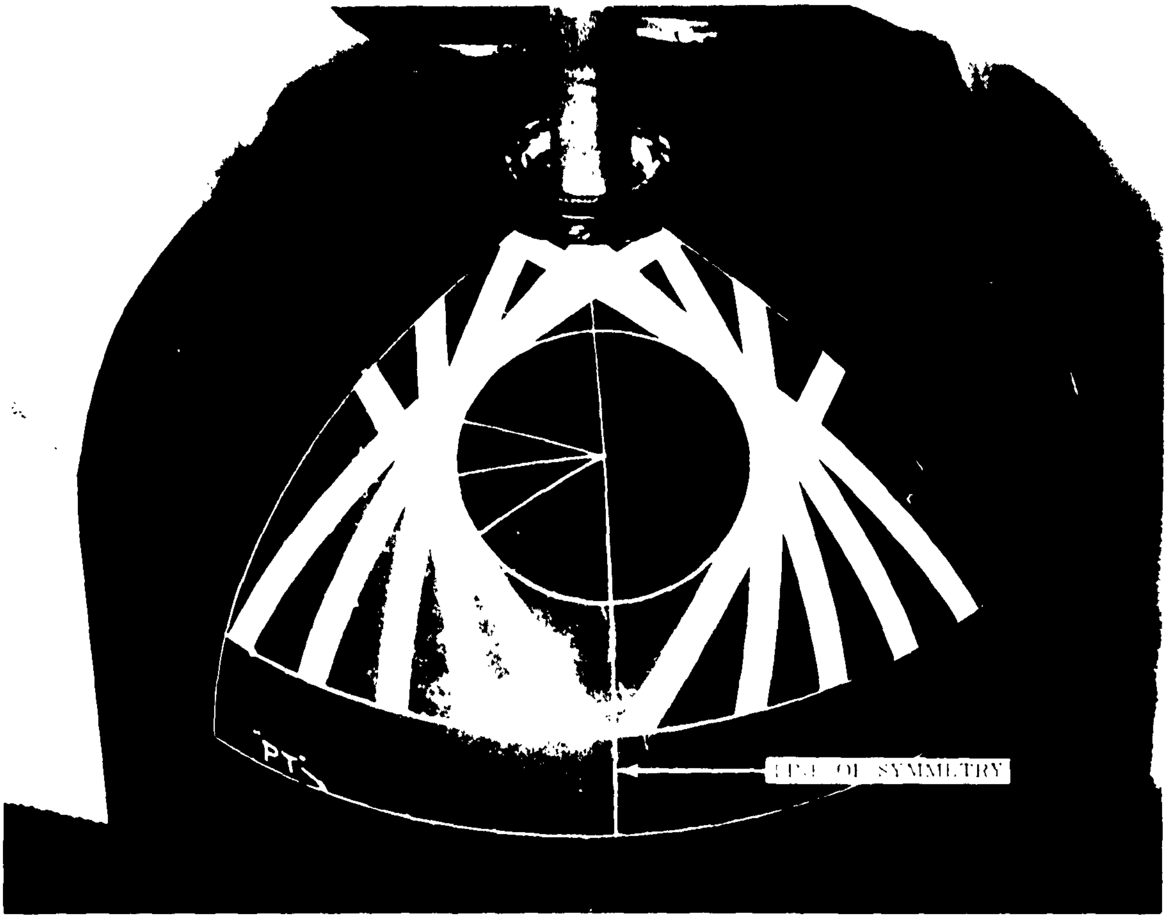


Figure 6-7. Construction Methods For Off-Center Port Reinforcements

SECTION VII

BENDING TESTS

It was required that some pressure bottles (7 inch size) be loaded in pure bending. In view of the fact that these pressure bottles did not have skirts through which the structure could be loaded, special end attachments were provided to properly load the structure. The methods which were considered most adaptable to this project for applying a pure bending moment were those used in "Wright Air Development Division Contract No. AF 33 (038) - 41872 and Navy, Bureau of Aeronautics Contract NOas 57 - 711 - f". The method used in the Navy contract was selected due to its adaptability to end connections which were compatible with filament winding techniques.

SPECIMEN FOR BENDING TEST

In order that a pure bending moment may be applied to the cylindrical section of the pressure vessel, it is necessary that either the end domes be cut off at points of tangency and plugs inserted in the ends of the tube, or that special end fittings be provided through which the bending moment can be transferred to the cylindrical section. If the bending moment were applied to the small on-center ports normally used with an ideal end-dome and a longitudinal filament orientation of 10 to 15°, the probable results would be either the de-bonding of the pole fitting or the failure of an end dome. In order to assure an adequate length of test specimen, it was decided to use a length of L/D of 2; however, it is mandatory that the winding configuration and construction be absolutely identical to the pressure vessel configuration which has an L/D of approximately 1. In order that the winding pattern and configuration be identical, it is necessary that the number of traverses of longitudinal material be maintained at 103, and that the shift in the end dome region be such that it advances eight spaces on each traverse.

It was elected to use an end dome pole piece which extends from the center line to the point of tangency. By using a conical end dome and selecting the proper cone angle, the required phase shift of eight spaces can be accomplished easily; thus the requirements of the same winding pattern configuration are maintained, and also an end dome flange which will transmit the pure bending moment to the cylindrical section is provided. By using a dissolvable mandrel, which is removed after the specimen is cured, no tolerance problems are encountered which would necessitate machining operations. With the bending moment applied through the I. D. of the conical pole pieces, the specimen may be tested by one of the standard bend-test methods, such as used in Navy Contract NOas 57-711-f. See Figures 7-1, 7-2 and 7-3 for bending test setup.

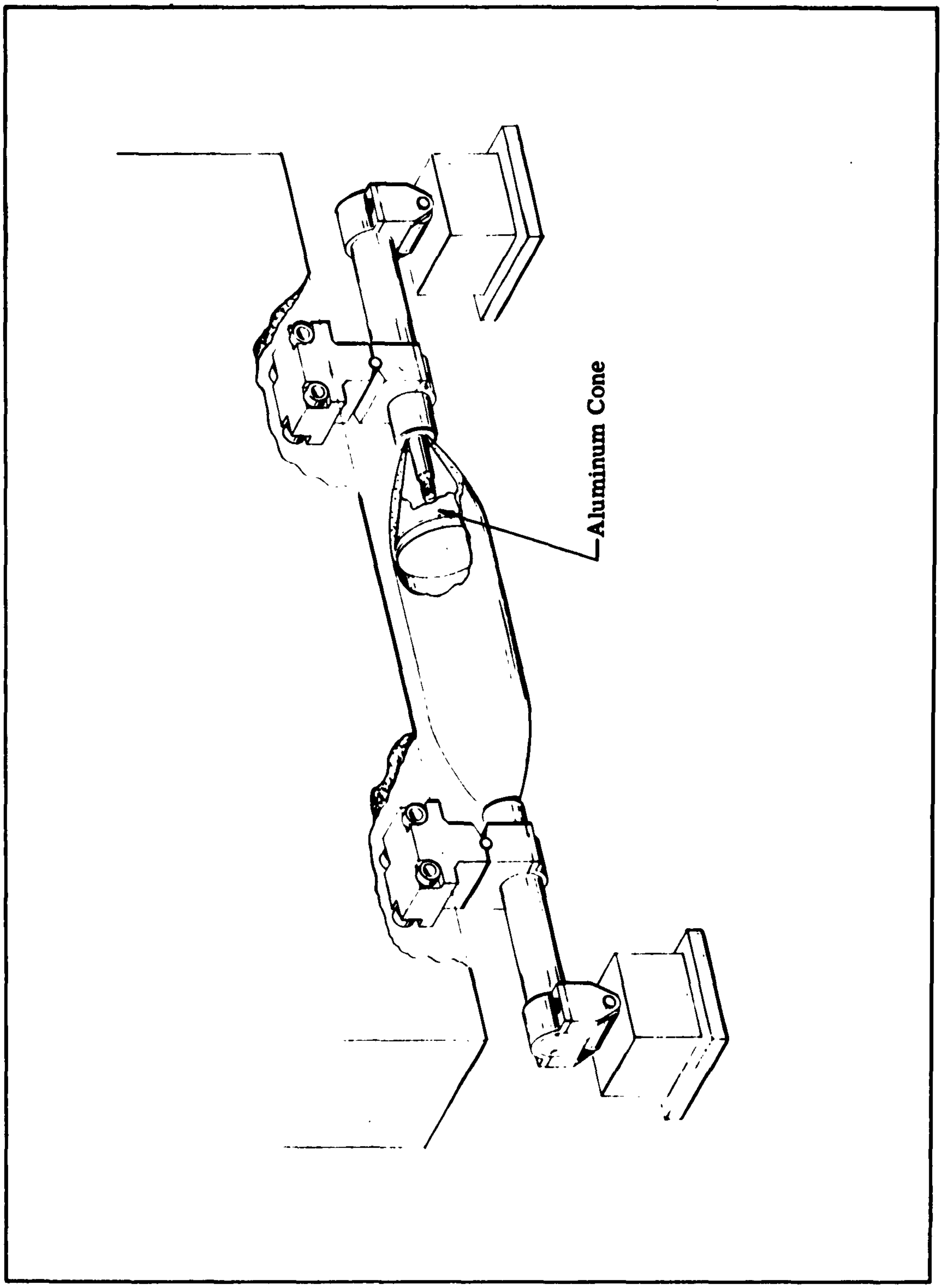
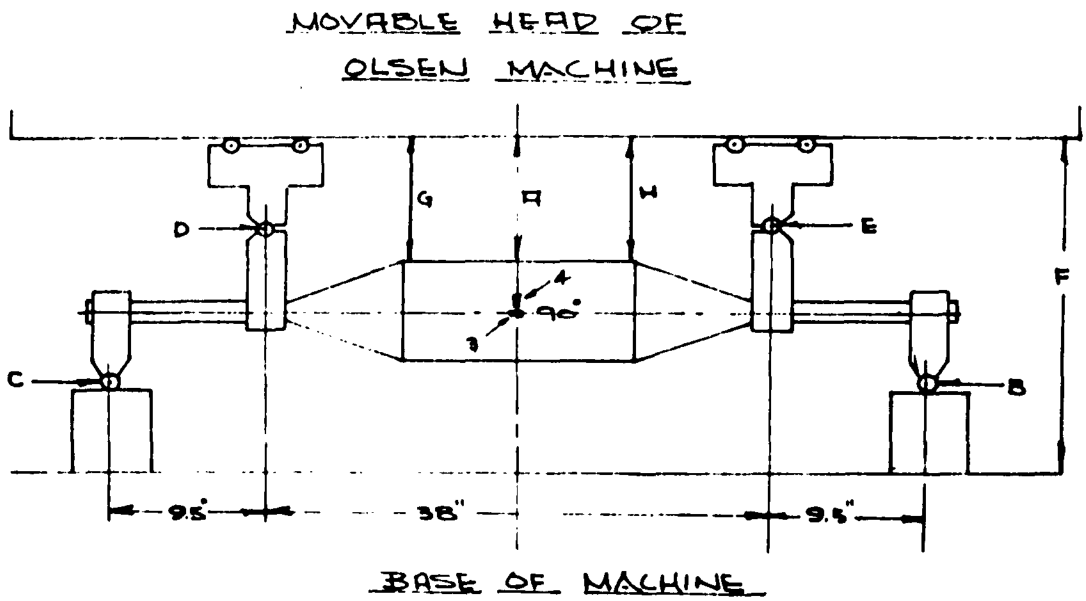


Figure 7-1. Setup For Case Bending Test



* STRAIN GAGES LOCATED ON BOTTLE AS FOLLOWS:

GAGE NO.	LOCATION	DIRECTION
1	0°	LONGITUDINAL
2	0°	CIRCUMFERENTIAL
3	90°	LONG.
4	90°	CIRC.
5	180°	LONG.
6	180°	CIRC.
7	210°	LONG.
8	210°	CIRC.

* NOTE: 0° POSITION AT TOP OF CASE.
GAGES PLACED MIDWAY BETWEEN P.T.'S

GAGES A THRU H ARE DEFLECTION GAGES.

Figure 7-2. Buckling Test Setup For 7 inch Fiberglass Cases

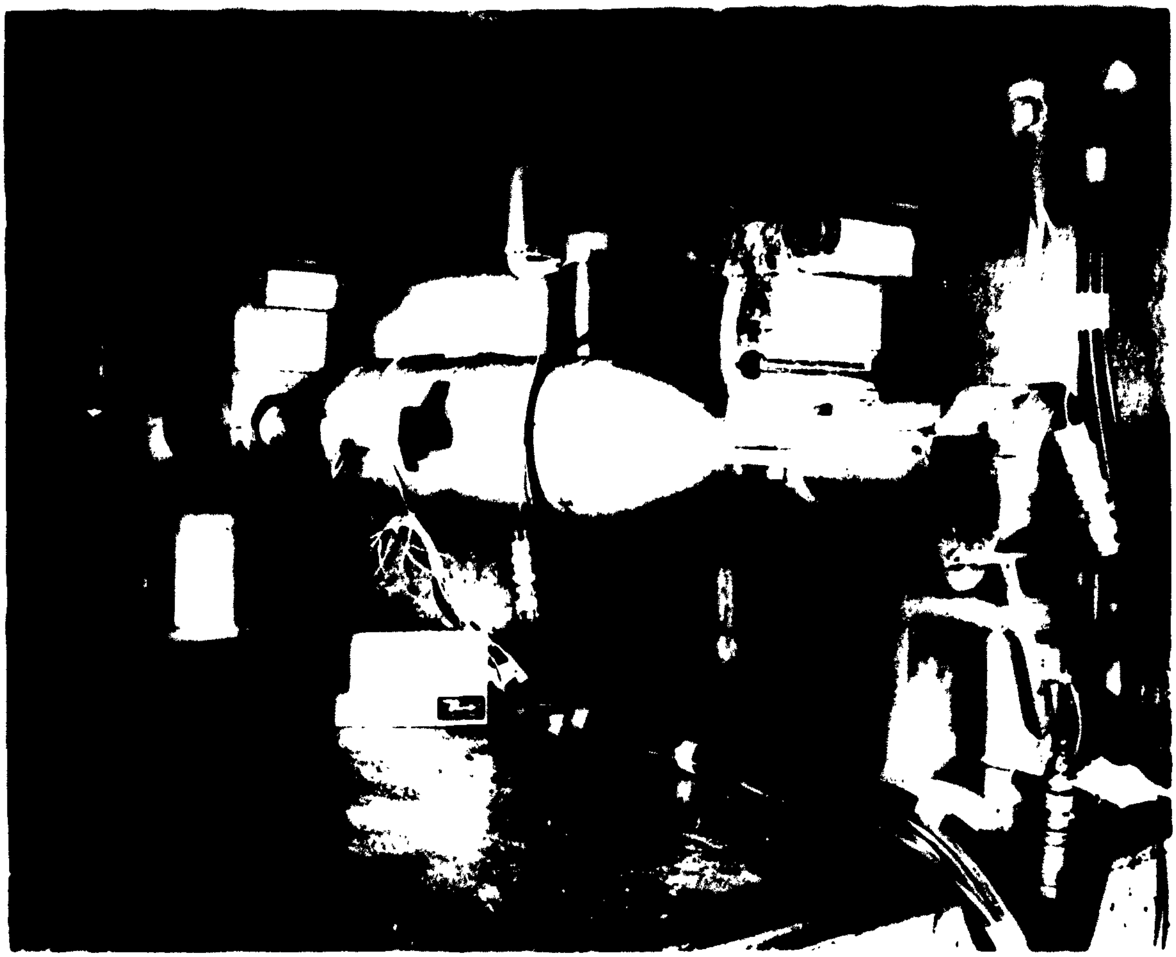


Figure 7-3. Photograph of Buckling Test Setup for 7 inch Fiberglass Cases

TEST RESULTS

The test was performed to determine the ultimate buckling load and strains in the case side wall. The pure bending test was conducted in an Olsen machine (See Figure 7-3).

Case SPN-11

Refer to Figures 7-4, 7-5 and 7-6.

The ultimate bending moment was 35, 000 inch-pounds.
Maximum strains were (-) 6690 micro inches.
(+) 4220 micro inches.

Failure was midway between the PT's in the cylindrical section.

Physical Dimensions

I. D. - 7. 170 inches
Unsupported cylindrical length - 15 inches
Wall thickness - 0. 057 inch

Material

Cordo 20 end pre-preg roving
ECG 140 (801 sizing)
Resin content - 16. 5% by weight

Construction (Same as SPN-06)

Circumferential layers - 4
Longitudinal layers - 4

Case SPN-13

Refer to Figures 7-7 and 7-8.

The ultimate bending moment was 37, 700 in. lbs.

Maximum strains were (-) 5080 micro inches.
(+) 5370 micro inches.

Failure occurred by buckling of the longitudinal filaments at the junction of the cone and cylinder.

Physical Dimensions

I. D. - 7. 170 inches
Unsupported cylindrical length - 15 inches
Wall thickness - 0. 047 inch

(text continued on page 7-11)

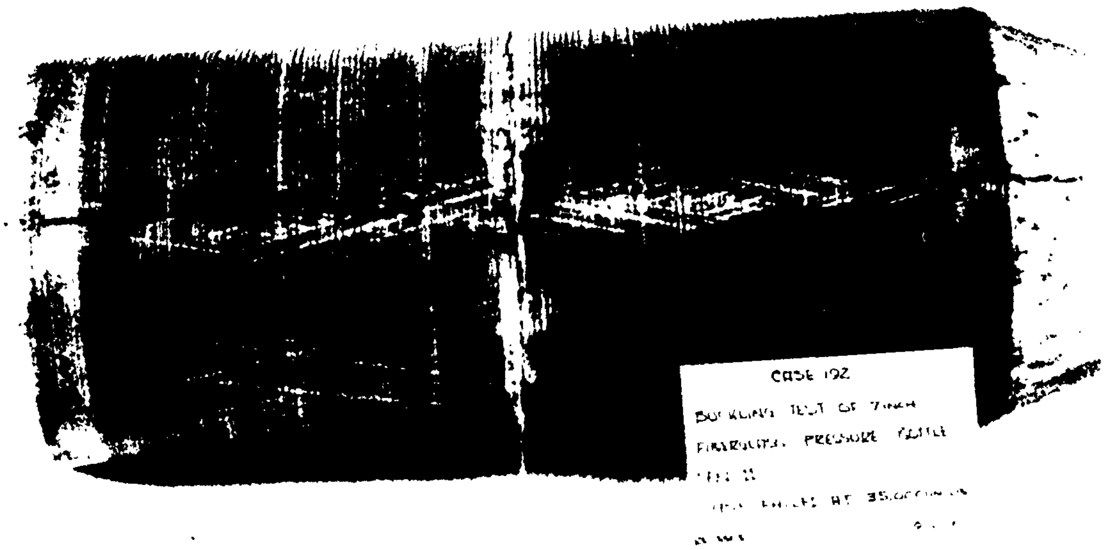


Figure 7-4. Case SPN-11 After Test - 0° Position

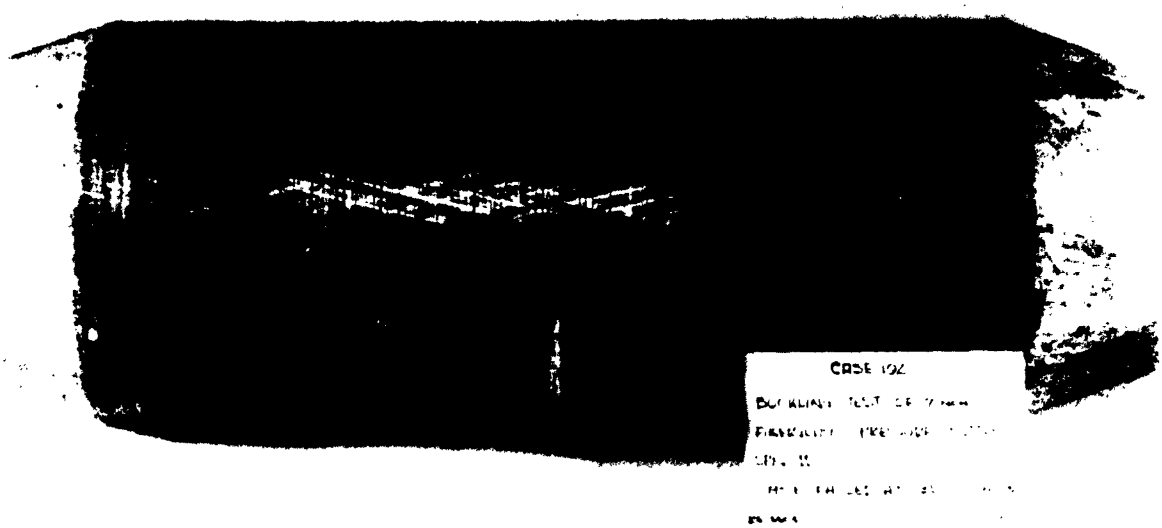


Figure 7-5. Case SPN-11 After Test - 180° Position

Load lbs.	* Moment Arm ins.	Moment Load in. lbs.	Strain Gages Strain in $\mu''/''$ 1	2	3	4	5	6	7	8	Deflection Gages ins. A	F
0	9.50	0	0	0	0	0	0	0	0	0	0	0
500	9.52	2480	-315	30	-90	0	245	-30	-20	-15	0	.036
1000	9.53	4760	-685	60	-60	0	640	-60	-40	0	.011	.067
1500	9.54	7150	-895	60	-75	-10	835	-60	-75	15	.016	.088
2000	9.55	9550	-1160	90	-60	-10	1130	-60	-75	15	.027	.112
2500	9.57	11,960	-1420	90	-60	-25	1375	-60	-95	15	.039	.145
3000	9.58	14,400	-1630	90	-60	-25	1620	-60	-115	30	.047	.186
3500	9.64	16,900	-1420	-265	-45	-35	1915	-90	-135	30	.074	.309
4000	9.73	19,500	-2265	-320	-45	-50	2260	-90	-150	30	.116	.521
4500	9.86	22,200	-2530	-115	-30	-50	2550	-125	-150	30	.124	.774
5000	10.06	25,200	-3850	-30	0	-50	2995	-125	-150	45	.217	-
5500	10.21	28,100	-4585	0	15	-60	3390	-155	-150	70	.306	-
6000	10.59	31,800	-5640	0	45	-75	3980	-155	-75	85	.407	2.44
6400	10.94	35,000	-6640	-90	75	-35	4420	-125	0	115	.504	3.20
6400 At Failure	10.94	35,000	-6690	-350	60	-75	4220	-125	-20	85	.501	3.18

* NOTE: Because the adaptors bent considerably during testing, these values are estimated.

Figure 7-6. Test Results of Case SPN-11

Figure 7-7. Case SPN-13 After Test

Load lbs.	Moment Arm ins.	Moment Load in. lbs.	Strain Gages Strain in $\mu''/''$								Deflection Gages Inches			
			1	2	3	4	5	6	7	8	G	A	H	F
0	9.50	0	0	0	0	0	0	0	0	0	0	0	0	0
1000	9.52	4670	-695	95	-40	-40	815	-85	0	55	.014	.024	.015	.030
2000	9.54	9540	-1295	150	-60	-85	1345	-120	0	65	.027	.039	.026	.081
3000	9.55	14,320	-1845	200	-105	-120	1825	-150	5	85	.040	.058	.040	.111
3750	9.57	17,950	-2340	235	-135	-155	2400	-175	15	110	.052	.077	.049	.162
5000	9.60	24,000	-3140	270	-175	-205	3260	-215	40	160	.073	.106	.068	.202
6000	9.63	28,900	-3880	295	-208	-245	4040	-250	75	195	.092	.135	.085	.273
7000	9.66	33,800	-4570	300	-240	-275	4750	-280	100	205	.113	.165	.104	.313
7775	9.68	37,700	-5080	270	-270	-285	5370	-295	130	95	.129	.179	.119	.343

Figure 7-8. Test Results of Case SPN-13

Material

Bendix fabricated tape
ECDE-300-1/0-1.0 T.P.I. yarn - EPS-4 sizing
Tape contained 46 ends - 0.213 inch wide
Resin content - 19.8% by weight

Construction (Same as SPN-12, 14, 16)

Circumferential layers - 8
Longitudinal layers - 6

ENGINEERING DISCUSSION

Specimen SPN-13 failed in an area which was not considered as part of the structure being evaluated. Figure 7-7 shows the longitudinal tapes failed in the end dome region where there were no circumferential windings to stabilize the structure. This area could be reinforced by a number of methods such as adding tapes or glass cloth.

SECTION VIII

STATISTICAL ANALYSIS

During the manufacture of fiberglass bottles, "D" rings were wrapped at various intervals during fabrication. These rings were cured and tested for quality control checks on the material going into the cases. After completion of 14 cases, the test results were analyzed to determine the correlation between "D" ring strengths and case strengths.

These data were divided into two groups. Cases that failed circumferentially were put in the first group and those that failed longitudinally were placed in the second. The maximum "D" ring strength was then used as the other variable and a line of best fit was drawn through the data by a "least squares" method. The whole process was repeated for the mean and minimum "D" ring stresses. The resulting lines were analyzed further and a coefficient of determination, r^2 calculated, and the conclusions listed in Figure 8-1.

	"D" RING STRESSES					
	Max.		Mean		Min.	
	corr. r^2	slope	corr.^{2} r^2	slope	corr.^{2} r^2	slope
Circumferential Failures (8 units)	0.2619	1.19	0.2633	1.0568	0.485	0.6614
Longitudinal Failures (6 units)	0.2197	0.5734	0.6693	0.3592	0.8391	0.3368

Figure 8-1. Case Failures vs. "D" Ring Stresses

As can be seen, the best correlation is with minimum "D" ring strength; however, for the circumferential strength, even this maximum is only 48%. This means that if 48% of the variation can be attributed to material strength, 52% must still be attributed to something else. And in addition, the analysis showed with 95% confidence that two of the sample values were from a different population.

Due to the small number of samples used and the wide spread in the data, the values in the table are not presented as conclusive evidence; in fact confidence that these values are right is quite low. However, the results do indicate rather conclusively (as would be expected) that increased material strength yields stronger cases. In addition, it appears that the average strength of materials is not nearly as important as the minimum strengths. Figure 8-2 shows the data for the circumferential strengths plotted against minimum "D" ring strengths. The figure shows the derived line and gives a feeling for the spread of data encountered. The conclusions then are (1) higher strength materials yield higher strength cases, (2) case strength is more sensitive to minimum "D" ring strength than to mean or maximum "D" ring strengths, and (3) correlation is low, indicating other factors have significant effects on case strength.

The confidence in the above analysis would be greatly improved by more tests. In addition, more tests would allow the examination of other constant cause systems; therefore it is recommended that additional tests be conducted and that the two "out-of-control" values be particularly examined in hopes of achieving major increases in strength with minor processing changes.

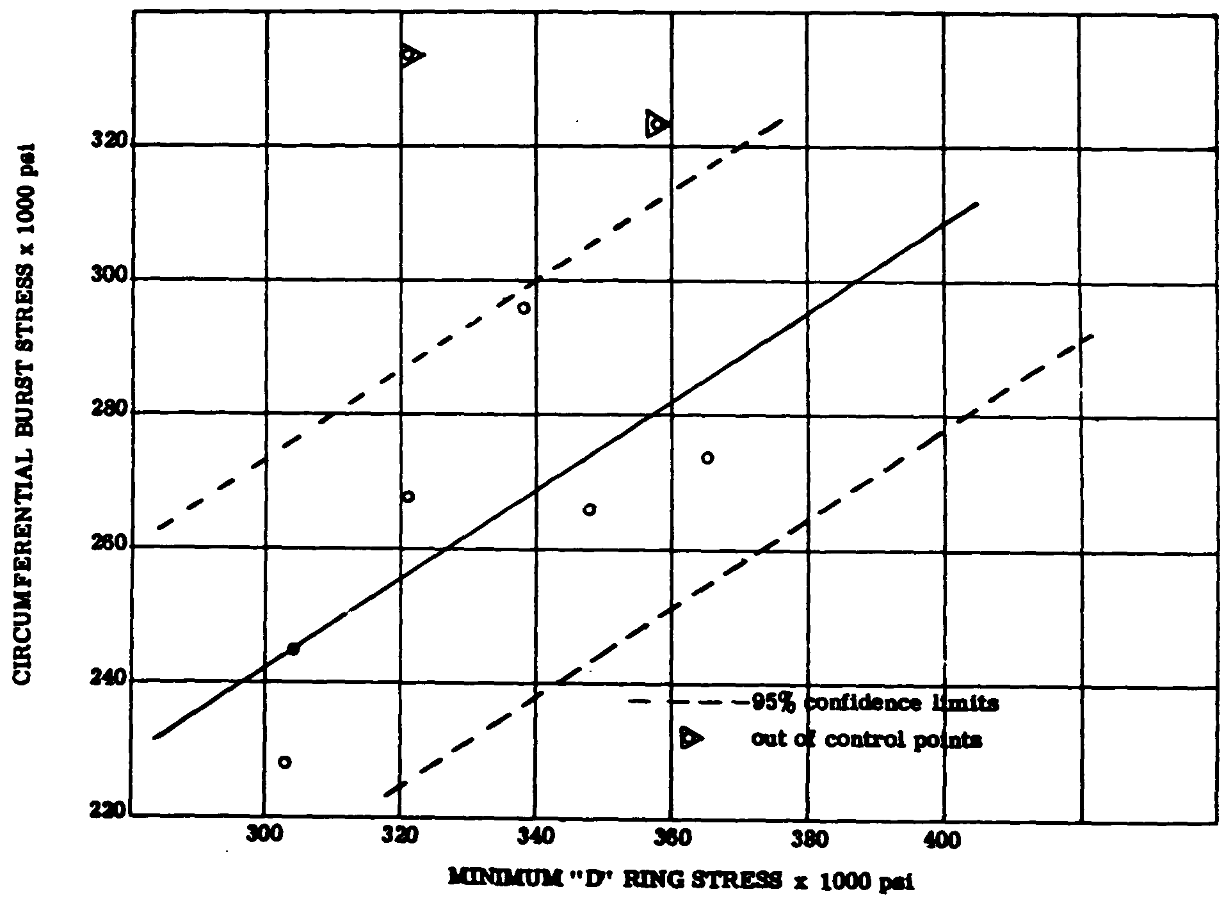


Figure 8-2. Circumferential Strengths vs. Minimum "D" Ring Strengths